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PRACTICAL SURVEYING

A TEXT-BOOK FOR

STUDENTS PREPARING FOR EXAMINATIONS OR

FOR SURVEY WORK IN THE COLONIES

BY

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"THE STATISTICS OF THE WATER SUPPLY OF GREAT BRITAIN," ETC.

WITH FOUR LITHOGRAPHIC PLATES
AND ABOUT THREE-HUNDRED-AND-FIFTY ILLUSTRATIONS

Seventh Edition

INCLUDING

TABLES OF NATURAL SINES, TANGENTS, SECANTS, ETC.

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PREFACE.

In submitting this little work to the Public, I take the opportunity of saying a few words in explanation of my object in compiling it.

My experience during several years past in delivering courses of lectures on Surveying and kindred subjects, and in preparing gentlemen for the Colonies, has shown me that, however excellent and comprehensive many existing text-books may be, they are in some points not sufficiently explicit nor in others sufficiently concise to enable the student, especially in cases of self-instruction, to grasp with readiness the subjects of which they treat. A text-book of somewhat different character seems, therefore, to be called for.

In the present work I have endeavoured to make each chapter complete in itself, and to let the chapters follow in progressive order.

I have also considered it better to explain the various instruments required in Surveying and their adjustment, before proceeding to describe their use and manipulation in the field. I follow then with a chapter devoted to a graphic treatment of Trigonometry as applied to Surveying; and the several succeeding chapters are intended to briefly

explain the *modus operandi* of Theodolite Surveying, Traversing, Town Surveying, Levelling, Contouring, Setting-out Curves, Office Work, and the Computation of Land Quantities.

In preparing the matter here presented, I have not only drawn upon my own experience, but have consulted many of the chief works upon the subjects in question, and I desire to acknowledge my indebtedness to the authors of the works thus consulted. I have also to express my obligations to the Astronomer-Royal, to Messrs. Troughton and Simms, and to Mr. J. H. Steward, for valuable information and assistance; whilst to my former pupils, Messrs. H. S. Fearon and James Holden, I am indebted for the surveys of Wimbledon Park and Cardiff. I wish also to acknowledge the assistance I have received from Mr. John F. Curwen, in the revision of the mathematical portions of the work as they passed through the press.

PREFACE

TO THE THIRD EDITION.

THE very substantial success which has been attained by this work—as seen in the sale of two large editions within a brief period—has been a source of great gratification. This has been enhanced by repeated testimonies, reaching me from all parts of the globe, that the value of the work has been felt by those whose avocations on public works necessitate such assistance as is to be found in the volume on the subjects of Levelling, Contouring, and Setting-out of Curves. I have felt this to be the more gratifying, as the work was designed rather as a text-book for students than for practitioners.

In view of this adaptability of the work, and in order to increase its usefulness, I have now added Tables of Natural Sines, Tangents, and Secants, with their complements. As thus enlarged, the volume should be found more extensively useful in the field.*

I have also taken the opportunity of the issue of a new

* To still further promote its applicability in this direction, the Publishers, at my suggestion, are issuing an edition printed on thin paper and bound in limp leather covers, so as to go conveniently into the pocket.

edition to revise and correct the book in a few particulars, and to bring it up to date by adding descriptive accounts and illustrations of several newly invented or improved instruments.

My warm acknowledgments are hereby tendered to the Proprietors of "Engineering," and to Messrs. Steward, Elliott, Stanley, and Cary, for the great assistance they have kindly given me in supplying particulars and allowing the use of blocks for illustration.

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PRACTICAL SURVEYING.

CHAPTER I.

INTRODUCTION.

"SURVEYING is the art of ascertaining, by measurement, the shape and size of any portion of the earth's surface, and representing the same, on a reduced scale, in a conventional manner, so as to bring the whole under the eye at once."

Subjects necessary to be known.—Such being the concise description of the science of surveying by an ancient writer, I am induced to inaugurate these pages with it. In the "Encyclopædia Britannica" it is argued that, "considered as a branch of practical Mathematics, Surveying depends for its principle on Geometry and Trigonometry;" and further, "it may be proper to mention the previous knowledge which a surveyor ought to possess, and to notice the instruments which he is to employ in his operations. As a surveyor has perpetual occasion for calculation, it is necessary that he be familiar with the first four rules of Arithmetic, and the rule of Proportion, both in Whole Numbers and in Fractions, especially Decimals, with the nature of Logarithms and the use of Logarithmic Tables, and with at least Algebraic Notation. As it is his business to investigate and measure lines and angles, and to describe them on paper, he should be well acquainted with the elements of Geometry and Trigonometry, and with the application of these principles to the mensuration of Heights, Distances, and Surfaces. In particular, he should be familiar with the best practical methods of solving the ordinary geometric problems, and should be expert in drawing lines and describing figures. He should be acquainted with the principles and practice of Levelling; he should know something of the principles of Optics and Magnetism and should possess at least a smattering of the arts of Drawing and Painting."

The foregoing remarks, from so eminent an authority, represent

more forcibly than any words of mine could the range of subjects which demands the attention of the student, and it will be my endeavour in the following pages to give them practical effect.

It is necessary, however, that I should traverse to some extent familiar ground, which I shall avoid where practicable; but I wish to make this work as complete as possible, and would therefore claim the indulgence of the reader if I seem inclined to be too elementary.

Standards of Measure.—In this country we are accustomed to what is known as the duodecimal system of measuring, whereof the foot of twelve inches is the basis. I do not propose to question the wisdom of continuing this standard in the face of the almost universal adoption of the metric system upon the Continent, and indeed nearly all over the globe; but I am bound to confess that the latter method, apart from its universality, offers greater facilities both in practical and theoretical application.

Chains.—For surveying purposes in England we have two kinds of chains, viz. the 100-feet and Gunter's. These chains, made of stout iron or steel wire, are composed each of 100 links; in the former case each link being equal to one foot in length, and in the latter 7·92 in., or 1-100th part of 66 feet, being the length of the link.

It will be manifest that the 100-feet chain has many great advantages, the chief being that it is so easily understood; and it is further argued that its increased length over Gunter is more conducive to accuracy in its use in the field.

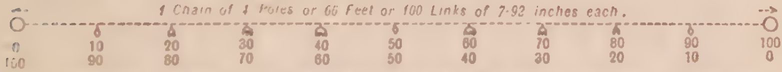
Advantages of 100-feet Chains.—For large plans of estates especially those destined for building operations, where every inch is of consequence, or for works of construction, the 100-feet chain will prove to be invaluable. But in the operations of surveying proper, for many potent reasons, pending the complete revolution in our system of mensuration, I must admit my preference for Gunter's chain.

Gunter's, or 66-feet Chain.—This instrument, if I may so call it, was invented about two hundred and fifty years ago by the Rev. Edmund Gunter, an eminent professor of astronomy at Gresham College (A.D. 1620). It is also called a four-pole chain. It is 66 ft. long (or four poles of 16½ ft.*), composed of 100 links of strong iron or steel wire, each link being 7·92 in. or 1-100th part of 66 ft. At every 10 links is fastened a brass tablet of different

* Poles, sometimes called perches or rods, in different parts of the kingdom, were formerly (by custom) of various lengths; as, of 15 ft. or 5 yds., 7 yds., 8 yds., &c. All these are now obsolete, and the statute acre (35th year of the reign of Edward I.), consisting of 160 square perches (of 272¼ square feet each), is general throughout England.

shapes to denote its value in tens, whilst at each end is a conveniently constructed brass handle.

Divisions of Gunter's Chain.—The first 10 links is distinguished by a tablet like this ; the 20 thus, ; the 30 thus, the 40 thus ; and 50 links or the centre of the chain (33 ft.) by a circular tablet thus ; so that from each end of the chain are tablets of similar shape and position, and the number of links is counted therefrom. But it is necessary to explain that, having reached the centre of the chain, or 50 links from one end, in proceeding to the other extremity, what represents 40 links from that end is really 60 from the commencement, and similarly 30 is 70, 20 is 80, and 10 is 90, whilst the handle represents 100 links. The following sketch may serve to illustrate this.



So that the 1st, 2nd, 3rd, 4th, and 5th labels represent 10, 20, 30, 40, and 50 links respectively from either end. A very little practice enables one to acquire a perfect facility in reading the chain.

Décamètre Chain.—The decametre chain is similar in construction to the Gunter, being divided into 100 links. Each 10 links equal a metre, or 3·2809 ft., so that a décamètre chain is 32·809 ft., or nearly the length of half of our Gunter.

Arrows.—Accompanying each chain are 10 arrows, or skewers, about 9 in. long, pointed at one end and having a ring * at the other for greater facility in carrying. These arrows are made of stout wire, and are used to mark upon the ground the end of each chain. The reason why ten is the number adopted is that ten chains (66 ft.) equal one furlong, and eight furlongs or eighty chains equal one mile. Again, an acre of land is ten square chains.

Offset Staff.—Besides the chain, the surveyor should be provided with a small staff or rod (called an offset staff), 6 ft. 7·20 in. long, divided into 10 parts or links. This staff should be made of well-seasoned wood, painted white, with black rings to distinguish the links; it should have an iron spike at one end and at the

* It is usual to tie a piece of red cloth or tape round the handle of the arrows, so that they may be the more easily distinguishable when stuck in the midst of grass or plants, &c.

other a stout open ring (as sketch, Figs. 1 and 2) for forcing or drawing the chain through a hedge.

33-feet Tape.—It is also advisable that the surveyor should carry in his pocket a small tape, say 33 ft. long, to be used *only* under circumstances when absolutely necessary. These tapes are divided into 50 links, similar to the chain.

Figs. 1 and 2.—Offset Staff.

Poles.—In order to mark out upon the ground any lines necessary for surveying purposes, poles from 10 to 20 ft. long, according to circumstances, must be provided. They should be $2\frac{1}{2}$ or 3 in. thick at the bottom, and taper to about 1 in. at the top. They should be shod with an iron shoe, pointed so as to easily penetrate the ground.

These poles should be made of well-seasoned deal, free from knots, and perfectly straight. Although it is an unquestionable advantage to have them painted (white, or alternate white and red, or black and white, according to fancy), yet it is not a matter of very much consequence, unless they are intended to be used again upon another survey, in which case the paint is a protection.

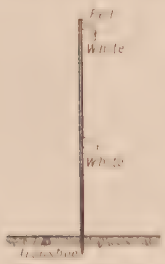


Fig. 3. Station Pole.

I prefer to surmount these poles with a flag about 18 in. by 14 in. square of red and white bunting, and it will be found extremely useful, especially for long distances, if a piece of white canvas is fastened by tapes half way up the rod (see Fig. 3). These poles are chiefly used for stations at the end of long lines. In some cases even these will not be long enough, when of course arrangements must be made according to circumstances, as will be hereafter explained.

Ranging Rods. No surveyor should be provided with less than about a dozen (or more if necessary) ranging rods, equally very straight and well seasoned to ensure against warping. They should be 6 ft. 7·20 in. long, with iron shoes at the bottom, and tapering from $1\frac{1}{2}$ in. to $\frac{5}{8}$ths of an in. in diameter,* and should be divided into ten equal parts (one link each), and painted alternately black and white, or black, white, and red, or red and white, and I have known them to be painted blue and white (this of course is entirely a matter of fancy). Red and white flags should be fastened at the top and white flags tied half-way down.

* I have a strong preference for my rods to be octagonal in section in preference to circular, as I think the arris of the former is of great assistance in ranging out lines.

The reason why I recommend them to be 6 ft. 7·20 in. long is that they are none the worse for being a little longer (some surveyors have their rods only 5 ft. long), and in the absence of an offset staff they may be used for all such purposes.

Bundle of Laths.—I always instruct my men to provide a bundle of laths, as not only are they light in bulk, but are "cheap and plenty," and have the advantage (if judiciously selected) of being fairly straight, easily sharpened to a point, and your chainman will not object to carry a dozen or so about with him. For ranging out a long base or other line, especially over very uneven ground, they are simply invaluable. Being white, they can be seen at a great distance, and when done with, if left on the ground, it is not a very serious loss.

Whites.—These are very necessary adjuncts to a survey. Varying from 15 in. to 3 ft. in length, they are simply thin sticks cut from a wood or hedge, as straight as possible, pointed at one end and having a cleft cut in the other for the purpose of inserting pieces of white paper. These are very useful in ranging out lines or for establishing stations.

Equipment of a Surveyor.—I do not know whether it is at all necessary that I should offer any suggestions as to the personal *habillement* of a surveyor, for my own experience has been that I have found the oldest clothes (sound, of course) the most suitable, as it leaves one enjoyably indifferent to the accidents that frequently happen to one's garments. Climbing over fences and walls, crawling through hedges, ascending trees, or fording a stream are not constituted to improve one's clothes if they are required for further use.

I may say, however, that, presuming it to be absolutely necessary to provide an outfit for surveying, the following may be a useful guide. First and foremost, good, strong, and unquestionably water-tight boots, with plenty of hob-nails, are imperative, for, apart from risk to health, wet feet for a greater part of the day, especially in winter, do not conduce to comfort or improve the temper. High-top boots are a great mistake, for not only do they impede the free action of the feet and are clumsy, especially in heavy land, but if one has to work in water, the act of stooping to obtain a better sight of an object may defeat the original intention of keeping the legs and feet protected from wet. Leggings are also a mistake, as they may keep the external wet out, but they also keep the perspiration in. Woollen cord trousers with leather gaiters are the most suitable for any field work. A jacket of good pilot cloth with plenty of pockets is better than anything, for it will stand many hours' exposure to wet. On no account do I recommend the use of a mackintosh, as it is always in the way if not wanted for wear, and

is constantly being torn; and I maintain that, except for driving, the mackintosh is anything but desirable. I will conclude my personal remarks by advising the use of a soft felt or cloth cap with as little brim as possible, as hat-brims are found, especially in instrumental observations, to be not only a nuisance, but often dangerous.

Field Book.—The surveyor should be provided with a good field-book, for which stout blue paper is generally the best. Some surveyors prefer an oblong book about 8 in. by $4\frac{1}{2}$ in., ruled with two lines down the middle forming a central column, on either side of which may be made sketches of fences, buildings, or other objects right and left of the chain-line; but I prefer a quarto book about $7\frac{1}{2}$ in. by 6 in., of which I shall have more to say presently. It is advisable to carry several spare pencils (F) in the pocket in case the one being used is lost; but to guard against such a contingency it is useful to tie a piece of string at the end (taking care to cut a notch round the head), and fasten it to the button-hole of your coat, with a sufficient length of string to enable you to manipulate the pencil. The same advice applies to a small piece of india-rubber, which it is always necessary to have. A good clasp pocket-knife is indispensable, not only for sharpening the pencil, but is very useful for cutting sticks, &c. I strongly recommend the young surveyor to carry a pair of good field-glasses, slung by a strap over his shoulder, as he will find them exceedingly useful, indeed on a large survey absolutely necessary. In the absence of a prismatic compass (to which, of course, preference is given) it is desirable to have a pocket-compass, to determine the bearings of points of the survey. It is quite as well to carry a scale, 6 in. long, of say two chains to an inch; a pair of pocket-compasses, a plentiful supply of white paper, string, a few nails, a lump of chalk, and last, but not least, a fairly-sized plumb-bob. I may also say that I have found a pocket-whistle exceedingly useful to attract the attention of my men when beyond the range of one's voice.

I have thus endeavoured to enumerate some of the chief accessories of a surveyor, all of which I maintain are essential for the due and satisfactory accomplishment of his work, especially as he may be, and often is, miles away from any place where such desiderata can be obtained. Remembering this, the student will not think my directions and suggestions too minute or trivial.

CHAPTER II.

ORDINARY SURVEYING.

Before proceeding to describe the *modus operandi* of surveying in the field, I wish to offer a few remarks upon the important question of *reconnoitre.*

Reconnoitre.—It is absolutely essential that the surveyor should, as a first step, make himself thoroughly conversant with the surroundings of the ground he has to survey, by walking all over the estate, whereby he not only gains an intimate knowledge of the various boundaries, the position of buildings, streams, &c., but is enabled to form an accurate idea of the best routes for his principal lines. It has, indeed, been argued that such a proceeding is unnecessary, occupying as it does valuable time; but the question is whether it is not an absolute saving of time to lay out the work so systematically, that, when chaining operations commence, there is likely to be no hitch or delay, by reason of encountering obstacles not previously observed which involve extra work or, possibly, the abandonment of an important line in consequence. One thing is surely important, and that is, to establish the principal stations, which can only be done after a careful examination of the ground.

Sketch Map.—In making a reconnaissance of a proposed survey, it is desirable to make a neat sketch of all the chief features, so that, having determined the routes of your base and other lines, you may delineate them upon this sketch and number them consecutively, which will be found to be of the greatest assistance, not only in subsequent field operations, but in plotting the survey.

Stations.—To make a survey of even a simple field, equally with an extensive estate, it is necessary to establish stations at those points to which it may be desirable to run lines. Thus A B C and D (Fig. 4) represent stations which comprehend a complete investiture of this figure, whereby lines from A to B, B to C, C to D, and D to A will be necessary to enable the boundaries of the field to be taken.

Fig. 4.—Stations.

Main Stations.—Stations are of a twofold character, main and subsidiary. Main stations represent those chief points which,

whether the figure to be surveyed be regular or irregular, embrace such lines as will command the boundaries of the survey. These stations are shown in various ways, according to circumstances. If the survey is of only a temporary character (such as can be executed in a single day) then poles or ranging-rods may be fixed for the purpose, but if required for an extensive survey, then stout pegs should be driven into

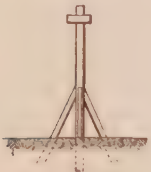


Fig. 5.—Fixed Station.

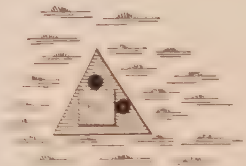


Fig. 6.—Station Mark.

Fig. 7.—Station Peg.

the ground, whilst in some cases special posts, built up and well strutted into the ground (see sketch, Fig. 5) may be necessary. If pegs are used they should be 5 in. to 8 in. long and 1¼ in. square, driven with about 1½ in. standing out of the ground, and in pasture land the turf should be cut round them in the form of a triangle (see sketch, Fig. 6). In order to easily identify these pegs I usually cut off a corner of the top (see Fig. 7) and mark the top with a letter corresponding with the sketch plan.

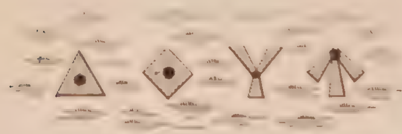


Fig. 8.—Station Marks.

Upon an extensive survey a large quantity of pegs will be found necessary—any local carpenter will gladly make them for a shilling or fifteenpence per dozen—and their value is incalculable. Temporary stations (required the same day) may be established by whites or marks on the ground. In pasture land, it is customary to cut the turf in some conventional form (such as shown in sketch in Fig. 8); but under all circumstances I confess to a predilection for pegs. If pegs are placed in the ground to denote stations where a line is to be run thereto, the peg should in due course be drawn and a ranging rod or pole put in its place.

Subsidiary Stations.—Subsidiary stations have reference to those points upon the base or other main survey lines, where it is necessary to run auxiliary lines, to pick up the boundaries of internal fences, &c., and are determined according to circumstances, as the process of chaining the main lines is carried on. If in

the case of an ordinary field (Fig. 9), when after chaining A B and B C, we proceed to take up C D, it will be necessary at *c* to have a station, and similarly on line D E to do the same at *d*, for the purpose of measuring the "tie" or "check" line *d e*. Anticipating my remarks upon the field-book, each station should be marked round with a circle or oval.

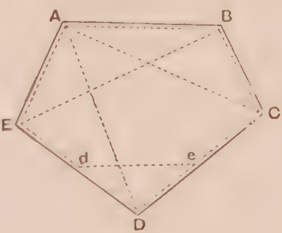
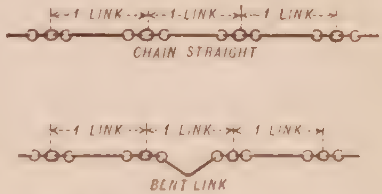


Fig. 9.

Testing the Chain.—Before commencing chaining, the surveyor should satisfy himself as to the accuracy of his chain, as, it if has been used before, either from constant pulling through fences, or other causes, it may become elongated, or, in going over rough ground, by treading upon some of the links they may become bent, and consequently shortened, as in the accompanying sketch.



Test Gauge.—To form a test gauge upon an even surface, preferably a pavement, it is desirable to measure accurately with a rod (the larger the rod the better) 33 ft. and 66 ft. in the same lines. These lengths should be tested by measurement from the other end, and having been determined, marks should be cut in the pavement with a hammer and chisel at each end and in the centre. In the absence of pavement, upon level ground drive in stout pegs, 66 ft. and 33 ft. apart, and having accurately gauged the two lengths, drive nails into the pegs to mark the exact points. A test gauge should be established in close proximity to every surveyor's office for constant comparison; but in a large survey it is desirable to make one close to the scene of operations, so that each day before commencing work the chain may be applied, and if longer may be adjusted by removing one or more of

the connecting links, or, if short, by straightening the wire links.

It may be stated that a Government standard of all kinds of English measures has been established in Trafalgar Square, by means of permanent bronze marks, let into the granite plinth of the terrace wall in front of the National Gallery. There is also a standard in the Guildhall, belonging to the Corporation of London; and in nearly every city and town in the kingdom, the Borough Surveyor has arranged certain marks wherewith to test his chains, and these, on a courteous request, will doubtless be put at the service of any surveyor whose avocations may call him into the neighbourhood.

There is an art in doing up and throwing out the chain. In the former case, the chain should be taken at its centre (with the circular tablet) and gradually each pair of links towards the end should be cylindrically folded diagonally over the last until the handles are reached, so that when tied up, the chain represents almost a wheatsheaf. The accompanying sketch (Fig. 10) shows the chain folded up and the arrows.

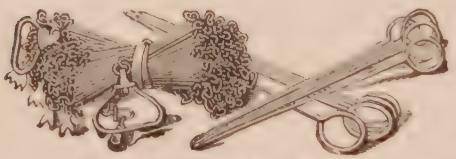


Fig. 10.—Chain and Arrows.

In throwing out, the handles should be held in the left hand with a few links loose, whilst the rest of the folded chain is held with the right, and by this means thrown smartly away, retaining hold of the two handles.

Chain-men.—Now, in all chaining operations, there is one person to drag the chain, called the leader, and another to follow, called the follower. Of these two (supposing two men are employed to assist the surveyor) the follower should be the more intelligent and trustworthy.

I would here say, that in all organised surveys there should always be ample assistance. I mean, that two men at least are requisite, so that the surveyor may be free to make observations, sketch, and enter measurements in his field-book, and generally superintend operations. Indeed I go further, and express a firm conviction, that it is real economy to have a third man, or an intelligent lad, to fetch and carry rods, to take charge of plans, books, &c., and generally to act as aide-de-camp.

Leader's Duties.—Reverting to the leader and follower, it is necessary to instruct each in their respective duties. To the leader should be explained, that, at the commencement of work he is to receive (and count for his own satisfaction) the arrows, for

which he will be held responsible. His duty is to precede the follower in a direction indicated, and to draw the chain gently after and upon reaching the limit of its length, he is to turn half round to face the follower, holding the handle of the chain in his hand, with one of the arrows between the outside of the handle and the inside of his hand thus (Fig. 11), and to watch for a signal from the follower as to how he should move laterally right or left, taking care (on his part) to keep the chain straight, by gentle shaking up.

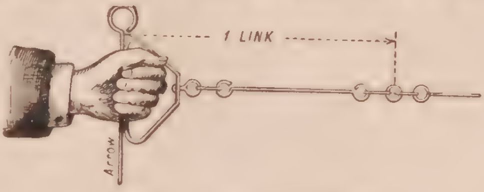


Fig. 11.—How to hold Chain.

Some surveyors hold that the leader should completely face the follower at the end of each chain, but my experience has been that, by so doing, his body often obscures a forward point, and by very little practice, he can be made to do the work as well sideways. It is necessary that he should hold the arrow perfectly upright, and only move it gradually right or left, so as to mark the exact spot indicated by the follower.

Here I may say, that it is useful to range out several points in a line by means of laths or whites, which will be useful in guiding the leader to keep in the direction it is necessary to go. The surveyor must impress this upon him, as I have sometimes found that the leader will elect to walk in a certain direction, apparently to his own satisfaction, which has the disadvantage of being considerably out of the line.

Duty of Follower.—The duty of the follower, having previously had the destination of the line explained, is to retain the other end of the chain in hand, and to direct the leader as to the direction he should take; to call out when the chain is at its full length; to hold the extremity of the handle against the centre of the station whence the line starts, or against the arrow which had been previously placed in the ground (taking care to hold the outside of the handle against the point); to see that the chain is stretched perfectly straight and lies evenly in a true line with the forward station; to direct the leader to move his body altogether right or left, and when approximately in line, to instruct him by slight lateral movement of his hand, right or left, until the exact point is obtained. If within hearing range he should call "To you" or "From you," or if beyond earshot, by moving the head right or left; and to convey to the leader that he is right, and it is necessary to fix an arrow in the ground to mark the spot, either call out "Mark," or convey that meaning by a nod.

In the event of it being found impossible to make the leader hear your directions or those of the follower, if you want him to move to the right, waive your right arm backwards and forwards, and, if to the left similarly with your left arm; and to indicate that he is in a right position, bring both arms smartly to attention.

How to use the Chain.—It should here be explained that as the chain measures 66 ft., or 100 links, between the ends of the handles, it would not be right to hold one extremity against the arrows or pegs at each end, for, by so doing, the length of the line is diminished by the number of half-thicknesses of the arrows or pegs, corresponding with as many chain-lengths as have been measured. But when pegs are used, if the end of each handle is held in the centre—or with arrows, if the leader holds the inside of his handle against the arrow, whilst the follower holds his handle (outside) against the arrow at his end—by these means the proper length may be adjusted.

After placing an arrow in the ground at the end of the first chain, the leader proceeds in direction of the goal, until he has reached the limit of the chain. The follower, having walked to the first arrow, and held his end of the chain thereto, now directs the leader so as to mark the second chain, which having been duly accomplished, the men go forward (the follower having previously picked up the first arrow), and so they continue, until the leader has expended all his arrows, when, having placed his last in the ground he calls out "Ten," which should be acknowledged by the surveyor and booked accordingly. The surveyor now proceeds to the tenth arrow, and putting his offset staff in the place of the tenth arrow, the follower, having reached this point, picks up the tenth arrow, and, with it counts the ten arrows, before handing them over to the leader, who on his part, again counts them to see that he receives the right number.

The foregoing is a description of the method of chaining a simple line between the points, supposing it to be necessary only to ascertain the length of a line, but it seldom happens, even in a check-line, that such an operation can be performed without crossing through hedges or fences of some description.

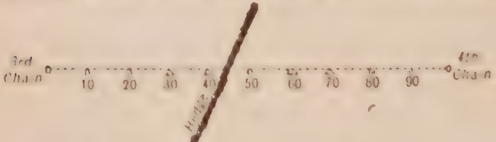


Fig 12.—Chaining through Hedges.

Crossing Hedges, &c. (Fig. 12).—In these cases the leader and follower must wait before moving forward, to allow the surveyor to note the chainage of such intersection. For instance, if after three chains have been measured a hedge intervene between the third and

fourth chain, then the follower, noting at what point the leader's end of the chain should pass through the hedge, gives the necessary directions, which having been done, the chain is now pulled tight, and a fourth arrow having been adjusted in place, the chain is allowed to rest until the number of links is ascertained where the fence crosses the chain. In the case supposed (Fig. 12) the number of links is 47, so that the crossing of the hedge on our chain-line should be booked 3·47ths.

Hedge and Ditch.—Here it may be well that I should speak of hedge and ditch, which appears to be a question somewhat enveloped in mystery. If I stand in a field with the ditch on my side of the hedge, then I know that the field in which I am standing reaches only up to the edge of that ditch, and that both the ditch and hedge belong to the field on the other side, as per sketch (Fig. 13). Thus the boundary of A is the edge of the ditch on the left, whilst the ditch and hedge belong to B. In illustration of this, when a railway is staked out through a district, it is usual for the contractor to fence in the land required for the works by means of what is called a "post-and rail fence" (see Figs. 14 and 15), which represents the extremity (on either side) of the property acquired by the company; and one of the last things done before the completion of the railway, is for the contractor to cut a grip or ditch, on the inside of the fencing, and with the excavated soil to form a mound in which "quick" are set. The life of the larch post-and-rail fence is supposed to be long enough to enable the quick to develop into a hedge. And in future years, when decay shall have removed the wooden fence, a surveyor will make the necessary allowance outside the hedge for the real boundary of the railway.

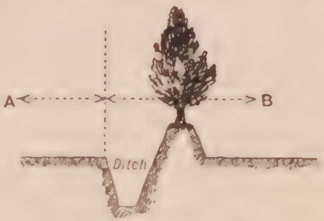


Fig. 13.—Boundary of Field.

Fig. 14.—Boundaries.

Fig. 15.—Boundaries.

How to measure Fence.—Here I would say, that it has been found to be more convenient to take all measurements to the centre, or root, of the hedge, and to make the necessary allowance

for the edge of the ditch therefrom. The usual allowance is six links, but in different counties in England this length varies according to custom, and it will be prudent of the surveyor to make inquiries in the locality as to that custom. This allowance of six links is, of course, upon the square as A B (Fig. 16) —for, if the chain crosses in an oblique direction (as C D) then the distance will be greater. For instance, suppose the edge of the ditch on the square is six links, as A B, but the chain crosses instead at an angle of 30°, then the length from the hedge to the edge of the ditch will be twelve links instead of six.

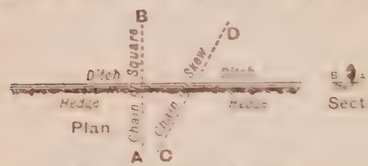


Fig. 16.—Skew Chaining.

Foot-set Hedges.—It may happen that a hedge has a ditch on either side, or none at all, and yet divides two properties, and in such a case the centre or root of the hedge should be taken.

Offsets.—The process of surveying, after the necessary lines have been laid out, consists of determining the various boundaries, buildings, &c., by means of lateral measurements, to such points right or left of the chain-line, as may distinguish any alteration in shape of the fence, or the angles of the buildings.

These lateral measurements are called offsets, and strictly speaking are always taken at right angles to the chain-line. As it is possible upon the ground, no matter how uneven, to lay out a straight line, which on paper is drawn with a pencil and straight-edge, so it is possible also upon the ground to set out a right angle. Under the head of "Instruments" (Chap. III.) I have described the cross-staff (p. 29), and optical square. I have described these appliances for setting out a right angle; and for taking offsets the latter will be found to be the most useful and accurate. But for general work, the surveyor soon gets accustomed, with the eye alone,

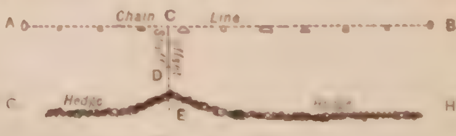


Fig. 17.—Offset.

to find the exact position on the chain at right angles to any clearly defined point. A greater help is to lay down the offset staff, and place it as nearly perpendicular as it is possible to judge, and then, looking along the rod, to mark with the eye any point in line therewith in the fence, as shown by the dotted line D E (Fig. 17)

when A B is the chain, G H the fence, and E a point at which it is necessary to take an offset; C D is the staff, and E F the offset. In using a cross-staff, great care has to be observed that the rod on which it is fixed is in a vertical position,* and exactly upon the chain-line. The top is directed so that two of the slits are in line with the chain-line at a b (Fig. 18) when, by looking through c d in direction E F, we have a right angle with A B.

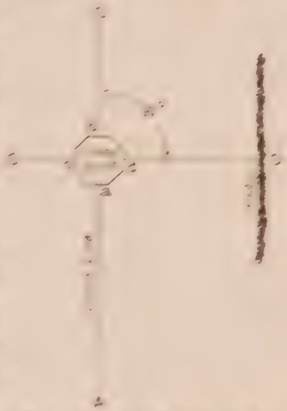


Fig. 18.—Offset with staff.

Using the Optical Square.—In the case of the optical square, the operator holds the instrument in his left hand, and having placed a flag at C or a piece of paper in the hedge, walks along the chain-line keeping his eye upon the advanced flag B until the flag or mark at C becomes coincident with the flag B (see in Fig. 20), when E C is at right angles with A B. Fig. 19 illustrates the better method of taking an offset at the intersection of two hedges C, with an

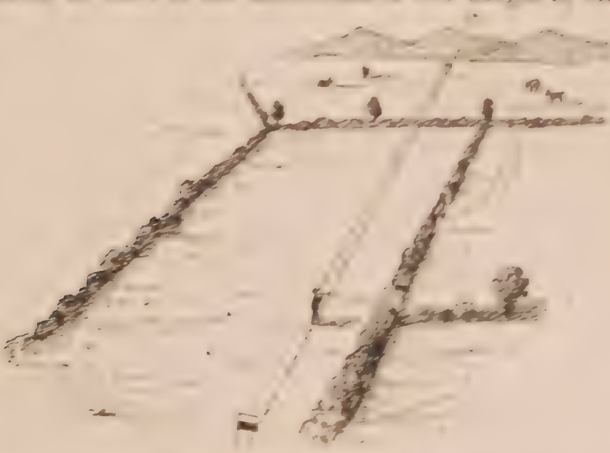


Fig. 19.—Offset with optical Square.

optical square, where A and B are the flags on the chain-line and C the point of observation.

* Equally with the necessity to fix the cross-staff perfectly vertical, so should all ranging rods be made perpendicular, which is best effected by using a plumb-bob.

Offsets should be taken at all points of divergence in the line of fences, or at angles formed by two fences. It is not necessary to take offsets at every chain if the hedge is fairly straight, but may be done every second or third, but when there is any appreciable bend or kink, as in Fig. 21, it will be desirable to take offsets at 1*a*, 2*b*, 3*c*, 4*d*, and 9*f* on the right-hand side of the chain, and 6*e* on the left. It will be seen, that the fence from *d* to *e* crosses the chain diagonally, as does that from *e* to *f*, and in addition to the offsets 4 *d*, 6 *e*, and 9 *f*, the distances along the fence 5 *d*, *e* 5, *e* 7, should also be measured, and to fix the corner *f* a temporary station in the chain-line as at 8, should be noted, and the distance 8 *f* measured as a check. If the ditch is on the other side of the hedge to the chain-line, then it is customary to take the offset to the centre, or root, of the hedge and add six links for the edge of the ditch, and if the ditch is on the same side, either to take the offset to the edge, or to measure to the root of hedge, and deduct six links. I may here say that unless the ditch be very wide, or the hedge inaccessible, I always prefer to measure to the hedge and deduct for the ditch, as denudation, or other causes, renders the edge of the ditch of a very undefined character, and if strictly taken in offsetting would not fairly represent the true boundary.

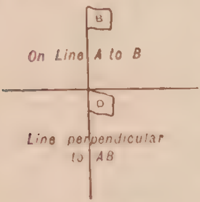


Fig. 20.

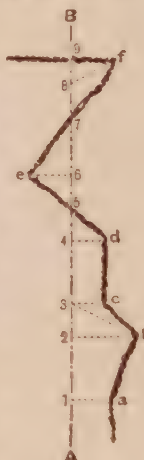


Fig. 21.

As to Buildings.—Buildings require to be very carefully taken at each angle, and the right angle must be very accurately set

Fig. 22.

Fig. 23.

out; in the case of Fig. 22, when a building is square with the chain-line, it is only necessary to take offsets to the face of the building. It will be seen that after the third chain, at 309 and

334 are points whence the two corners of the building run, and the difference between 309 and 334 should be the same as measuring along the face of the building, viz. 25 links. All that is necessary is to measure the depth of the building together with any projections that may occur, as in Fig. 22.

In the example shown by Fig. 23, keeping the same points on our chain-line, it will be seen that the first offset at 309 is to 1, which is the angle of the back of the building, whilst 314 to 2 is the front corner, 326 is the termination of that same plane, 329 the angle formed by the projection at 4, and 336 the other angle of the same plane. The lengths of the frontage, sides, back, and projection, should be measured carefully, and the various angles of the buildings should be fixed by diagonal tie lines, as shown in Figs. 22 and 23.

Fig. 24.

As to taking Corners of Fields.—In the case of commencing a chain-line in the corner of a field, as in Fig. 24, it is not sufficient to take one offset from A to *a′* on line 1, and one from A to *e* on line 4, to obtain the angle *b* formed by the two fences, but the diagonals A *b* and *a b* are necessary to accurately fix the point of intersection. Equally, when the chain-line crosses the fence at *c* it is not only necessary to take one offset at *d* to *c′*, but the length c c′ along the hedge should be measured, so that with the length c *d* on the chain we have a triangle to fix the exact position of c′.

Fig. 25.

Fig. 26.

To fix Position of an Intersection.—It may happen that the intersection of a fence on the other side of the hedge requires to be accurately determined, for which purpose a simple offset would hardly be sufficient. Set out a triangle, with one side on the chain, as in Fig. 25, as *a* at 320 and *b* at 337, and then measure the length *a c* and *b c*. And again, to fix the angles of a building when a right angle is deemed insufficient, as in Fig. 26, leave stations A B and C at 304, 315, 347, from which measure the lengths A *d*, B *d*, B *b* and C *b* to the corners of the building.

Limit of Offsets.—Now as to the limit of offsets, I may say that I do not agree with many writers who recommend offsets of 100 or 200 links, or even more, nor do I approve of the use of a tape for such a purpose, except under exceptional circumstances. In a well-known work on surveying I was surprised to read that "Offsets may be measured by pacing, with a tape, or with one offset staff. We prefer the last, although for preliminary or parliamentary work we generally measure by pacing, and the student will find that after a little practice he can measure his offset *by pacing quite as near as he can plot the work.* Of course it is understood that we have to get ourselves into the habit of pacing a yard at every step." Now, I need hardly say, that I most emphatically condemn every word of the foregoing advice, as being entirely contrary to what is required of the surveyor of to-day.

Pacing.—It is true that military surveyors are in the habit of pacing and sketching to a very great extent, and even for "kadastral" purposes have been known so to train their horses that a cavalry man can form a very fair approximation of distance by counting the number of paces the animal makes. I elect to quote from an eminent military surveyor * upon the subject of pacing, who says: "In such surveying as an officer is generally called upon to perform, sketches of small positions, reconnaissances, &c., he will of course be unprovided with a chain, and must determine the length of the base by pacing or counting the paces of his horse." But even this recommendation is qualified by the remark that approximation is sufficient. I certainly have yet to learn with what degree of satisfaction, not to say accuracy, the offsets for a survey of any importance can be done by pacing, even upon perfectly level ground. I recommend the student in surveying of to-day to keep forcibly in mind the maxim that "a thing that is worth doing at all is worth doing well," and any trouble involved in taking his offsets in the proper way, will be amply repaid by the accuracy with which his work is accomplished.

Objections to Tapes for Offsets.—My objection to a tape is threefold: 1st, it is conducive to laziness and long offsets; 2nd, after much use or wet it either elongates, or in windy weather it is shortened by sagging; and 3rd, it is an intolerable nuisance either to keep winding up, or to have to gather it in folds in your hand, added to which, the filthy state in which it makes your hands and book. Further, after continual usage, either by dirt or wear, the figures get indistinct, and this often leads to errors.

I have said that I do not approve of long offsets, and I think 50 links should be the maximum, unless under very exceptional

* Major W. H. Richards.

circumstances. Long offsets are generally the result of laziness, for rather than set out a small triangle from a chain-line, when a considerable bend in a fence occurs, and from the sides C E and E D of this triangle take short offsets, as shown in Fig. 27, many surveyors who advocate long offsets would take to the bend direct from the chain-line A B. And here let me say that a triangle such as C D E cannot be considered correct unless a tie-line such as C′ E is measured.

Fig. 27.

Offset Staff.—I need hardly say that I recommend the use of an offset staff for taking offsets, feeling persuaded it is the most accurate and convenient method. And the staff is useful for determining a right angle, as well as to pull the chain through hedges, &c. To use the offset staff, lay it with one end against the chain, and looking along it, note any point in the fence where a line produced would cut, and then turn it over carefully, so that it does not slip back, to prevent which, place your toe against the end, and so on until you have reached the point. A little practice will soon render the task simple.

Ranging out Lines.—Having determined the position of the main and chief subsidiary stations, it is now requisite to range out such lines as may be necessary to proceed with the survey. Poles or rods having been placed at the extremities of lines, the lines themselves should be "boned-out," which is accomplished by sending a man forward with laths or whites, and the surveyor, placing himself at some little distance behind a rod, at the commencement of the line, is enabled to range as many intermediate points as he may deem necessary. I strongly recommend standing, say two or three yards away from the rod, as a much better sight is obtained than by being so close to the rod. It is advisable

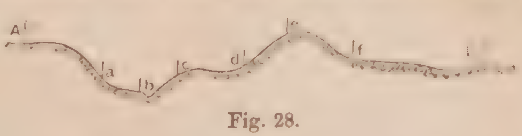


Fig. 28.

to range out a number of intermediate points, especially in undulating ground, as, not only may it not be possible to command the forward station if in a valley, but they are extremely useful in guiding both the leader and follower in the chaining operations, This is illustrated in Fig. 28. If A and B represent the stations of a line which has to pass across a valley, it is manifest that unless

such points as *a b c d e* and *f* have been previously established, it would be impossible to chain the line A B. And here it may be well to say a few words upon the question of measuring along sloping ground.

What is Level Ground.—Any ground of a fairly level character may be treated as being quite level—that is, any ground whose slope does not form a greater angle with the horizon than five degrees. But beyond this, it is necessary to adopt some means of regulating our measurements. If we take a pair of compasses, as in Fig. 29, and with A as a centre and B (the foot of the slope) as a radius, and strike the arc B C until it cuts the horizontal line A C, it will be seen that the line A C is greater than A *b*, *b* being a point whence a perpendicular is let drop to cut the foot of the slope.

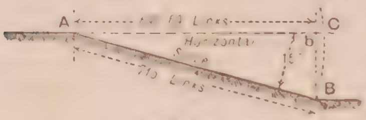


Fig. 29.

Now it is well understood that in surveying operations all measurements upon the ground are reduced to the horizontal, as, "when plotted the survey represents a perfect plane, and in chaining the lines they should be so conducted, that every length should be a point exactly equal to the base of a right-angled triangle."

In the case of Fig. 29, if we plotted the line A B exactly as measured along the slope, which in this case is 715 links, we should make our line 24·31 links longer than it should appear, and consequently our plan would be inaccurate. I make no apology for reproducing the following well worn simile to illustrate my meaning. If we take a staircase composed of 30 steps, each tread being 12 inches wide, and each rise 6 inches, strictly speaking we could only show them as the plan of a house by a length of 30 feet, whereas if we measure the string of the staircase it will prove to be 33·54 feet long. Thus I do not think any more need be said to emphasise the necessity of reducing *all* measurements to the horizontal.

Now there are several ways of doing this; chiefly by reducing the hypotenusal measure by calculation, having obtained the angle of slopes, and by "stepping." Of the former, much may be argued for and against, and I propose to say a few words on both sides. Of such a method there can be no doubt that for expedition a great deal may be said in its favour. With an Abney level or clinometer it is very simple indeed to observe the angle of slope and to make the necessary reduction in the chainage as the work proceeds. But the very greatest care and discrimination is requisite in determining these angles. It very seldom happens that the slope of a hill-side is regular; on the contrary, it is often made

up of constantly varying inclinations, some flat, some steep; and to accurately determine the hypotenusal correction separate angles will have to be observed at each point of variation. Fig. 30 will better illustrate my meaning, for between A and B it would not be sufficient to observe the angle formed with the horizon by A B, because to be correct, the hypotenuse should be measured along the line A B, whereas (being impossible) we follow the undulations of the ground between these points, such as A *b c d e* B, and use the length so measured as the multiple of the angle of slope. Thus, whereas the line A *b c d e* B measured along the surface of the ground is 720, the angle A B C (the angle of slope with the horizon) being 25°, the hypothenusal deduction would be 72·38 links, whereas strictly speaking it should only be 70·50 links, by reason of having taken the angle from A to B. So that, to be accurate, it is necessary to observe the angles of slope at A *b c d* and *e*, and for each separate angle to take the length along the slope between the points.

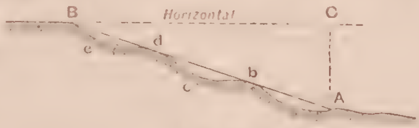


Fig. 30.

Observing Angle of Slope.—It has been suggested that to obtain the angle of slope it is sufficiently near to send a chain man to the point at which it is desired to take the angle, and to observe when the clinometer cuts his face; but if the surveyor happens to be a short man and the chain man tall, it is difficult to see how he is to obtain accurate results. I recommend the use of a sliding vane similar to Fig. 31, which should be adjusted to the

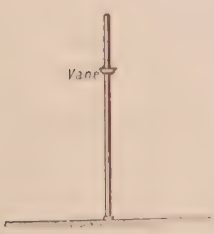


Fig. 31.—Slope Staff.


Fig. 32.—Taking angle of Slope.

height of the eyes of the surveyor, and which being held perpendicular at any point, will give a true line parallel with the slope of the ground. Fig. 32 represents my meaning.

The following is a table of allowance to be made for the difference between hypotenusal and horizontal measurement.

Degrees.	Links.	Degrees.	Links.	Degrees.	Links.	Degrees.	Links.
5	00·4	14	03·0	23	07·9	32	15·2
6	00·6	15	03·4	24	08·6	33	16·1
7	00·7	16	03·9	25	09·4	34	17·1
8	01·0	17	04·4	26	10·1	35	18·1
9	01·2	18	04·9	27	10·9	36	19·1
10	01·5	19	05·4	28	11·7	37	20·1
11	01·8	20	06·0	29	12·5	38	21·2
12	02·2	21	06·6	30	13·4	39	22·3
13	02·6	22	07·3	31	14·3	40	23·4

Adjusting the Allowance for Slope.—It should be here explained that many surveyors, having calculated or obtained the necessary allowance, either move the arrows in accordance with the reduction from the length of slope, or make the alteration in the field-book; the former method, however, is best, as any offsets that may be required will be more favourably affected than by the latter. To use the clinometer a very steady hand is required, and possibly the best instrument for the purpose is the Abney level (described in Chap. III. p. 33); but a primitive and very useful little clinometer may be made by cutting a stout piece of cardboard into the shape of a semicircle and dividing it right and left of the centre into 40 degrees, each of which may be marked with the figures given in the table. It is held in one hand and held up to the eye, and looking along the diameter of the card you note when this line cuts the vane of the staff, when a small plummet hanging from the centre marks the angle, which should be read by one of your men.

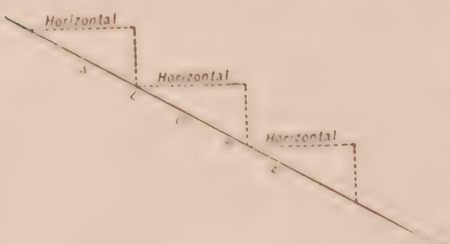


Fig. 33.

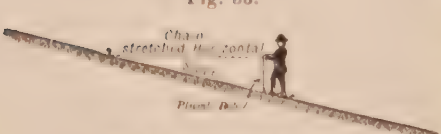


Fig. 34.—Stepping Slopes.

Stepping.—I venture to think, however, that if necessary care is observed, chaining up and down slopes may be accomplished with sufficient accuracy for all practical purposes by what is known as stepping, which consists of short lengths of the chain being held in a horizontal position, and the extremity transmitted to the ground by means of a plumb-bob, as shown in Figs. 33 and 34. The greater the angle of slope so much less with the horizontal distance, and *vice versa*, and

great care should be observed, not only in taking short lengths of the chain, but in accurately marking the exact point above the plumb-bob, indicating the end of the length after it has been brought to rest. I am of opinion that chaining may be accomplished along sloping ground both accurately and expeditiously by this means if the necessary care is observed, and it has the advantage of indicating absolutely the true position whence an offset is taken, rather than by calculation. I have had very extensive experience in measuring along the sides of hills, and have always found this system satisfactory. But it must not be supposed for a moment that I am an advocate for substituting for a plumb-bob staves or arrows dropped from the end of the chain, which is a very frequent custom.

Base Lines.—In all surveys, large or small, there should be base-lines intersecting the figure to be surveyed. The letter X is the best form for the base-lines to take, care being observed that their direction is upon as level ground as possible, for upon the correctness of the length of these lines the accuracy of the whole of the details depends. I have said tolerably level, that is to say, with no greater undulation than say 4 deg. to 5 deg., for gentle slopes have comparatively slight effect upon linear measurements, and if the ends of the base-lines are otherwise well situated, so as to command an uninterrupted view of surrounding country, the existence of such undulations in the intervening ground need not be considered a drawback. Base-lines should be as near the centre of the survey as possible, since the liability to inaccuracy in the triangulation increases with the distance from the original base. The base-lines (and there may be more than two, and only one under certain circumstances) should form the basis of a system of triangulation which comprehends the various boundaries of the estate. The equilateral is the best form of triangle, and it should be sought to lay out this figure as much as possible, but of course this is not always practicable. The sides of the triangles formed upon these base-lines are called chain or survey lines, which are so arranged as to take the boundaries of the property, and from these again are subsidiary chain-lines, to pick up any of the fences or other objects that intersect the estate.

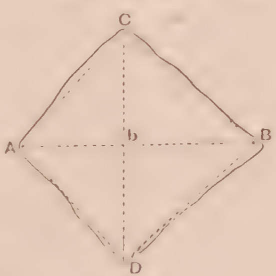


Fig. 35.

A very simple illustration of the base and survey lines will be seen in Fig. 35, in which A B is the main base-line and C D the other; the survey-lines are A C, C B, B D, D A. Now three sides of a triangle, however carefully measured, are no guarantee of its accuracy; there must be a proof or tie line. It has been recom-

mended to test the accuracy of a triangle by letting drop a perpendicular from the apex to the base; this is all very well on paper, but upon the ground it is not always either practicable or expedient. In Fig. 35, quite by accident the line C D crosses the line A B from the apex of each triangle A C B and A D B at as near 90 deg. as possible, consequently the length C *b* will test the triangle A B C, and *b* D will prove A B D.

I have borrowed an excellent example (Fig. 36) from a well-known work (on surveying) which illustrates my argument exactly, where it will be seen that the property consists of two fields adjoining a road, which are together in the form of an irregular triangle. The three sides A B, B C, and C A embrace the exterior boundaries, whilst the direction of the internal fence is of a character that a line E D may serve the double purpose of taking up this hedge and acting as a check to the triangle. For if the lengths A E on line A B and A D on the line A C be carefully measured, then the length

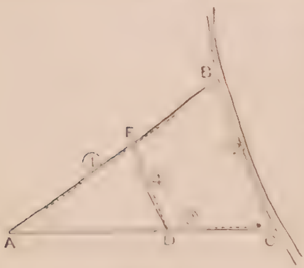


Fig. 36.

E D will be proved to fall exactly within these points after the triangle has been plotted.

Fig. 37 shows how the irregular figure A B C D E F may be divided into triangles, and by C F all four triangles may be tied, although I should recommend a further check, such as D *d*.

It does not always follow that a survey must consist only of triangles, although it is always advisable to adopt this figure when possible, for, as in the case of Fig. 38, A B C D is in the form of a

Fig. 37.

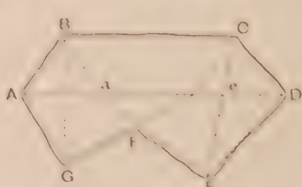


Fig. 38.

trapesium, and so long as the line B C is checked by such ties as B *a* C *e* the work will be all right. The line C *e* produced to E, checks the triangle *a* D F, as does a part of B G, the figure A *a* F G.

Chain Angles.—We have dealt so far with simple figures, whose outlines can be ascertained by running lines in various directions to take up the boundaries and intersecting fences, which lines are

checked by such means as I have briefly described; but there are cases, such as woods or ponds, in which it is impossible to get through or across, where it is necessary to chain round, taking the exterior boundary, and fix the relative directions of the lines circumscribing the figure by means of what are called chain-angles.

I have already explained that three sides of a triangle measured is no proof of accuracy, to ensure which a fourth or tie-line is required. This is all the more necessary in the case under consideration, where we have, as in Fig. 39, to run our lines all round outside, and have to prove our work. Here we have to tie our lines in such a manner as to comprehend the outline of the wood, through which it is quite impossible to survey. Briefly, to prolong lines 1 and 4 and to tie their extremities by the line A a would not be sufficient to ensure the angle, therefore a second tie a a' is necessary, and, similarly, lines 3 and 4 by means of the ties D d' and D d. The acute angle formed by lines 1 and 2, although tied by b b' (which serves the double purpose of a survey line), could hardly be trusted unless checked at the other extremity of 2 by the ties c c', c C, C c^2.

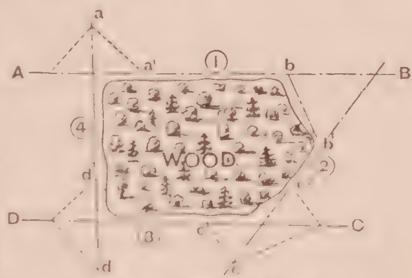


Fig. 39.—Chain Angles.

I might give numbers of instances of how such figures may be circumscribed by means of lines and chain angles, but in these days, when instrumental observations have superseded such methods, I deem it to be unnecessary to dwell upon the subject.

Inaccessible Distances.—It rarely happens that a survey of any extent can be carried out without some difficulties being encountered, such as base or important chain-lines being interrupted by obstacles, in the form of rivers, arms of lakes, ponds, buildings, &c., when it is necessary to resort to some means of working round in the one case, or by geometric construction, or angular observation to ascertain the intervening distance. This strengthens my argument in favour of reconnoitre previous to commencing a survey, as in undulating ground a building or other obstacle which had been unobserved might come directly in the line, which by careful arrangement beforehand might have been avoided. In the absence of any instrument, such as a box sextant or optical square, a right angle may be approximately set out on level ground by the following simple method. Measure forty links on the chain-line,

and put arrows, as at A and B (Fig. 40), then with the end of the chain held carefully at A take eighty links, and instruct another chain-man to hold the eightieth link at B; take the fiftieth link in your hand and pull from A and B until they are fairly tight, when an arrow at C will be perpendicular with the line A B, in other words A B will equal 40, B C 30, and C A 50 links.

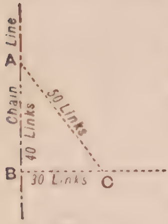


Fig. 40.

I have said this may be done approximately on level ground, but I do not recommend any reliance being placed upon a right angle set out in the manner above described if intended to overcome a difficulty such as is represented in Fig. 41, where the line A B is interrupted by a house. In this case it is assumed that if at *a*, on the line A B, a right angle be set out (as explained) and a sufficient distance *a* C, say 60 links, measured, and C D (made perpendicular to *a* C) 80 links, and D *b* at right angles to C D measuring also 60 links, and *b* B made perpendicular to *b* D, then *a* *b* will be within the points A and B, in other words in the same line, supposing the building did not obstruct. Thus four right angles have to be set out and measured to carry the line A B past the building. I recommend the student to practise this problem on perfectly level ground, and I venture to think he will agree with me that, unless the line *b* B has been ranged from A upon sufficiently high ground to see over the building, very little reliance must be placed in the prolongation of the line A *a* by such means as I have described, and yet there are numbers of works on surveying which give it as a practical example. I can only say that I should observe the greatest care in checking with a theodolite such work before I should trust to such a prolongation.

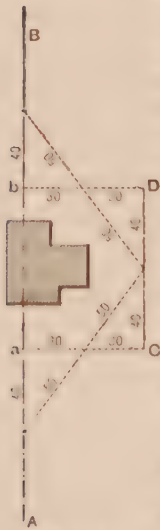


Fig. 41.

I have selected one or two such examples of measuring over inaccessible distances, across rivers or ponds, by the chain only, as appear to me to be capable of satisfactory results, if great care and accuracy be observed, for, unlike the case of the building, you can command all points. Suppose, as in Fig. 42, the line A B is intercepted by a river, the width of which is too great to ascertain by measurement across. We must therefore proceed to set out such a figure on one side of the stream as will enable us to range across it a line which shall so intersect the line A B, that this point of intersection shall be equidistant from a given point to another point, to which we are able to measure on the ground.

First, range the line A B across the stream, sending a man with rods to establish on the other side where directed in the first instance at B. From any convenient point b measure towards A such a distance as judgment tells to be greater than that across the river, say 400 links, at A the extremity of 400, and b, set out right angles, and from b measure 300 links to b', and from A 600 links to a'. Place rods at a' and b' (having previously checked the lines A b' and a' b' which should respectively be 500 links); now range through a' and b' the point c on the line A B, then c b' will equal a' b', viz. 500 links, and b c will equal A b, viz. 400 links. Measure from each edge of the stream to b and c, the sum of which deduct from 400, and you have the width of the river.

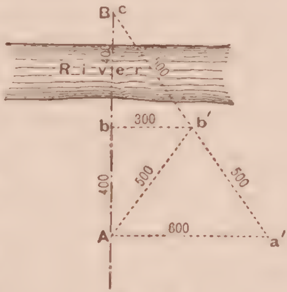


Fig. 42.

Again, in Fig. 43 at C on the line A B set out the perpendicular C D, and make it some equal number of links, say 400; bisect C D in b, and at D set out the right angle C D c, make D c = 300 links, place rods at c and b and range the line through until it intersects A B in B, then C B will equal D c = 300 links. Similarly, if the line passes obliquely (Fig. 44), set out any line parallel (approximately)

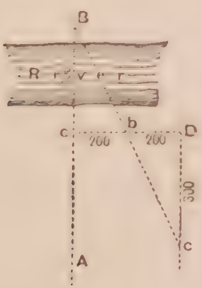


Fig. 43.

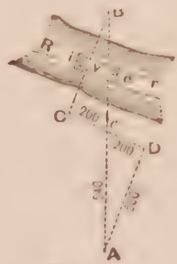


Fig. 44.

with the bank of the river, as C D, measure 200 links either way, at each end set off the perpendiculars D A, C B, then will c B = c A = 540 links. Again, as in Fig. 45, measure off the perpendiculars B C, D E, ranging the point C in line with A E; then

$$A\,B = \frac{B\,C \times B\,D}{D\,E - B\,C}$$

All the foregoing are fairly good methods of determining in-

accessible distances, in the absence of instruments for taking angles, but I need hardly say that the right angles should be set out with an optical square or other reliable appliance, and even then the very greatest care must be observed.

The simplest, quickest, and most reliable method of determining

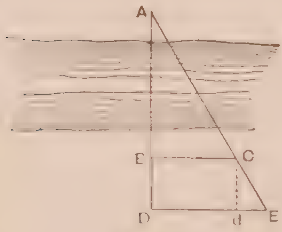


Fig. 45.

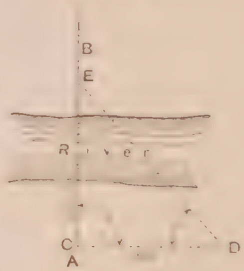


Fig. 46.

an inaccessible distance is as follows: (Fig. 46) at C, with a box sextant or theodolite set out the line C D at right angles with A E, measure any distance C D, and at D observe the angle E D C. Then

$$C E = \text{nat. tan. } E D C \times C D.$$

For example, the angle E D C is 51°, and the length C D = 450 links. Now nat. tan. of 51° = 1·2349.

∴ 1·2349 × 450 = 555·7050 links, which is the length C E. Should there be any doubt as to the accuracy of the observation or calculation, place the instrument at E and observe the angle C E D, which should equal 90° — 51° = 39.

I now leave this branch of my subject, as in subsequent chapters I propose to treat the whole question of field work in greater detail.

CHAPTER III.

SURVEYING INSTRUMENTS.

In the early days of surveying only very primitive instruments were available, but nowadays the science of surveying has attained such a state of perfection that we have instruments of all kinds for facilitating geodetical operations in the field.

Cross Staff.—In the foregoing chapters I have referred to the process of taking offsets with an offset staff, which for short lengths may generally be relied upon. Although I am bound in this division to refer to the cross-staff, I have no hesitation in condemning its use upon nearly every ground. I look upon such appliances as only an excuse for long offsets, against which I am very strongly opposed, and with such feelings I naturally discourage their use.

Fig. 48.

Indeed, apart from this prejudice, I cannot see any feature of recommendation in the cross-staff except for approximation.

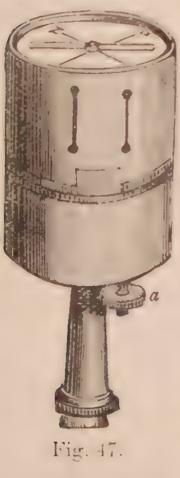


Fig. 47.

The cross-staff is made either cylindrical or octagonal in shape, about three inches in diameter (see Figs. 47 and 48) and five inches deep. It has slots placed at right angles to each other, in which are contained fine wires strained very true and vertical. In the octagonal staff there are also slots on the other four faces, which may be used for approximating an angle of 45 deg. The staff is fixed upon a rod (spiked at the end), and being placed perfectly perpendicular at a point on the line A B (Fig. 49), at which it is desired to set out a right angle, the slots *a* and *b* are adjusted so that, looking from *a* to B and back from *b* to A, the wires are coincident with the points A and B. Many cross-staves have a compass fixed at the top, as in Fig. 47, which—provided the staff

is accurately adjustel in a truly vertical position on the line—may serve to take the bearing of the line with magnetic north. There is a form of cross-staff, as in Fig. 47, which is so constructed that the upper part of the cylinder may be moved round upon the lower portion with a rack and pinion movement actuated by the screw *a*. A ring on the lower member is divided into degrees and subdivisions, and, with a vernier attached to the upper cylinder, it is possible—with the greatest care—to obtain the angle of one or more points, but this can only be regarded as approximate.

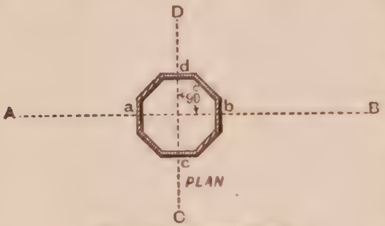


Fig. 49.—Cross Staff.

Some writers affirm that this instrument is valuable "for setting out base-lines, ... more particularly for crossing any high ground with a sharp ridge." I can only say that I should place very little reliance on the accuracy of any survey which depended upon a cross-staff, either for the prolongation of lines across ridges or even for setting out right angles.

Optical Square.—This is at once a most accurate and useful little instrument for its purpose, but it also must be used with great caution. All appliances of this character are liable to be used to save trouble—I mean they facilitate long offsets. The optical square (Fig. 50) consists of a metal box of from 1½ to 2½ in. diameter, formed by an outer and inner tube working one within the other, so that by a slight movement right or left the slots upon the outer tube are made identical with similar slots on the inner case, but which latter are so placed in fixing the two together that although capable of a slight movement they are held in position by a screw. This enables the instrument to be protected from dust or dirt when not


Fig. 50.

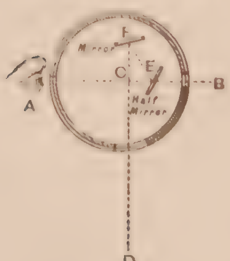


Fig. 51.


Fig. 52.

in use. Within this circular box are contained two mirrors (one of which is only half silvered, the lower portion being plain) placed at an angle of 45 deg. with each other. Referring to Figs. 51 and 52 it will be seen that the glass E is placed at an angle of 120 deg. with the line of sight or diameter of the box, and the mirror F is at 45 deg. with this. Now, by a well-known law, a ray of light in direction of A B falling on E will be reflected on to F at an angle of 60 deg. (F E C), which will be again reflected in the line F C, whereby F C is 90 deg. with A B. Thus, a person wishing to establish a point on his chain-line A B at right angles with some particular point, right or left, has simply to walk along the line in direction of B until the object at D becomes coincident with the forward station B. Thus supposing a white flag is placed at B, Fig. 53, and

Fig. 53.

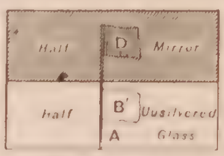


Fig. 54.

another flag at some distance further ahead, say B′ (for this is most important, as will be explained hereafter), and at the point D a red flag is fixed; then, provided the observer is in absolute line with B and B′ when D appears coincident on the upper half of the mirror E, the red and white flags will be as on Fig. 54. Again, if at any point on the chain-line, as C, Fig 53, it be necessary to establish a point at right angles, as D, instruct an assistant to move backwards and forwards until his flag is coincident with the points B and B′.

The Line Ranger.—This is a very useful little appliance for obtaining an intermediate station upon a line. It consists of two reflecting glass prisms placed one over the other, having two sides in the same plane so that the hypotenuse of the one is at right angles to that of the other. The observer holding the ranger in his hand and looking into the prisms in direction of G H (Fig. 55), if he is in a true line, the reflected image of a rod at his right hand on B on the prism E, whilst a pole at A on his left will be reflected in the prism F, "so that when these images are in the same straight line the instrument is also exactly in the same straight line with the objects A and B."

Clinometer.—The clinometer in its primitive state was simply an appliance for ascertaining the angle of a slope with the horizon,

the most simple being a card in the form of a semicircle, divided right and left of the line of quadrant into degrees and subdivisions

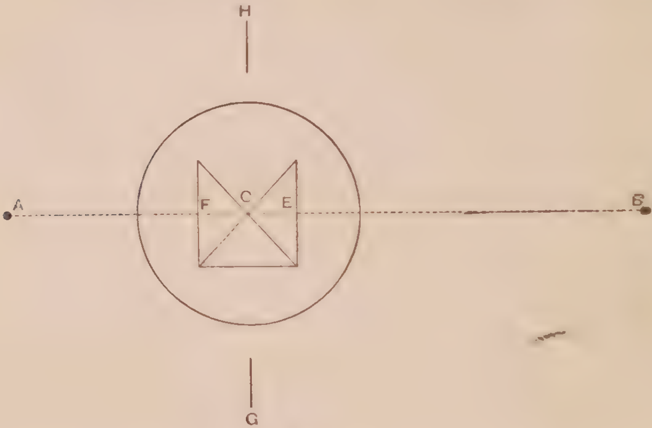


Fig. 55.

of a degree. With a small plumb-bob attached to the centre it is possible, by elevating or depressing the line of diameter, to read off the number of degrees, &c.

Merrett's Quadrant. A modification of the quadrant was invented by the late Mr. H. S. Merrett. It is made of boxwood, having two arcs (right and left) of 90 deg., divided into degrees and half degrees, being sufficiently clear for the purposes for which it would be required. It has two tables engraved on it, one to ascertain the height of any object, the other for shortening the hypotenusal line to the horizontal line, when required in surveying hilly districts the same as a theodolite.

There are also angles of slopes usually adopted in railway cuttings and embankments.

It is governed in its operations by a spirit level on the top, having two sights. The arc is divided both ways so as to enable the observer to read either for angles of acclivity or declivity. It is fixed upon a small tripod, whereby greater accuracy is obtained.

I have thought it necessary to explain briefly this instrument, but neither has it come into very general use, nor can it in fact compare with the many excellent instruments of modern days.

Clinometer Rule.—This is possibly one of the most simple and compact of the absolute instrument types. It consists (Fig. 56) of a box wood rule in two parts, with a hinged joint (like a sector) about 6 in. long when closed. In the upper arm a small spirit

level C is inserted, whilst at either end are fixed sights A and B with cross wires. Attached to the hinge is a brass quadrant F, which is divided into 90 deg. and minutes. A spirit-level D is also inserted in the upper portion of the lower arm G, whilst upon one

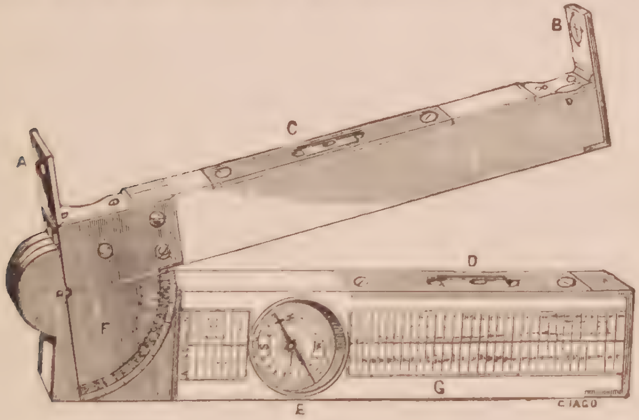


Fig. 56.

of the sides is engraved a scale and table of hypotenusal allowances, and the more complete clinometers are accompanied by a small compass F. In using this instrument for acclivity you sight from A to B, and for declivity from B to A.

The Abney Level.—This is a reflecting level and clinometer combined, and is deservedly popular amongst engineers and surveyors. A new form of it, introduced by Mr. Steward, is shown in the illustration below (Fig. 57).

It was invented by Captain Abney, and consists of a hollow

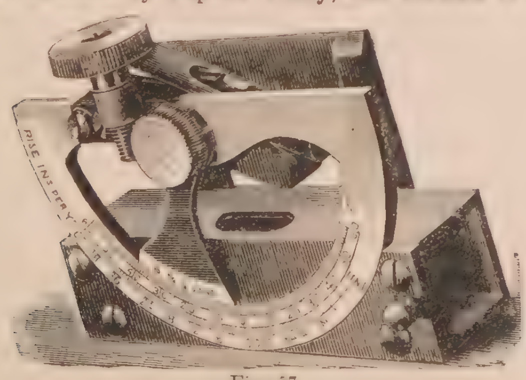


Fig. 57.

arm containing a telescope. Attached to this arm is a vertical arc, each quadrant of which is divided right and left into 60 degrees and subdivisions. The arm is of sufficiently stout metal to enable at its centre a horizontal spindle to be fixed, carrying a spirit-level, the case of which has a slot underneath, so as to expose the bubble, so that in whichever position the arm is held the bubble will be reflected on to the mirror. A vernier * fixed to the spindle and at right angles to the arm of the bubble indicates the relative angles of acclivity or declivity on the vertical arc. The instrument shown in the illustration is much more compact than the usual form, having a couple of telescopic tubes, which close up into the body of the instrument, and are drawn out when the level is to be used. Another new feature is the adjustment for moving the vernier arm and the bubble tube attached to it by means of a wormwheel fitted on the vernier arbor. This arrangement also gives room for a larger divided arc than usual.

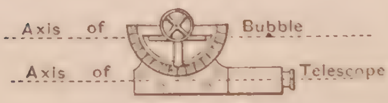


Fig. 58.

Referring to Fig. 58, it will be observed that the instrument in its entirety is in a truly horizontal position. Fig. 59 shows the instrument being used for the angle of acclivity (which in this case is 34 deg. 15 min.), and Fig. 60 that of declivity, or 19 deg. 30 min. with the horizon. Thus the level tube is always horizontal, and the arm of the vernier vertical, whilst the telescope assumes whatever

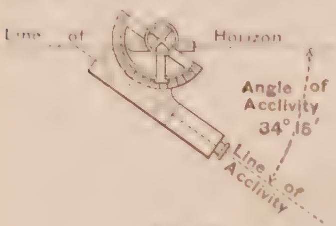


Fig. 59.

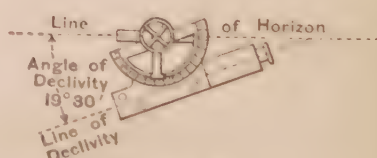


Fig. 60.

angle it may be desired to observe, and the vertical arc consequently has its zero varying in position accordingly.

The Abney level may be made to fit on to a tripod with a ball-and socket movement, whereby greater steadiness and consequently more accuracy may be attained.

Reflecting Clinometer Scale. This (Fig. 61) is somewhat on the principle of the Abney level, and has the advantage of being half the cost. It consists of a telescope with a mirror half silvered, to reflect the bubble into the slot. The vertical arc to which

* A vernier is fully described on p. 52.

the level-tube is attached rests in a triangular frame, and its outer edge is cogged, so as to be actuated by the pinion; and

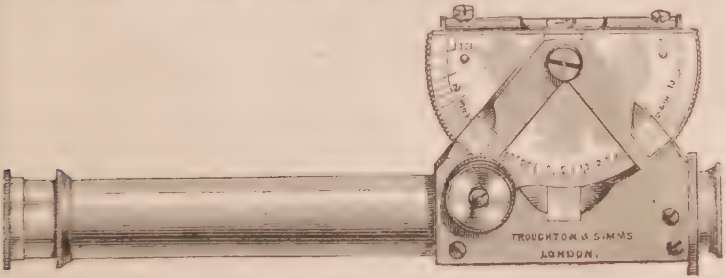


Fig. 61.

for some reasons this motion is preferable to that of the Abney level. The cost of this instrument is £1 1s.

Combined Telescope Clinometer and Prismatic Compass.—This is an extremely valuable instrument, and for ordinary surveys will serve the same purpose as a theodolite. It has one great advantage, and that is, it can be attached to a light tripod, so that it may be accurately adjusted over a station.

The instrument consists of a bronze box C, about 5 in. in diameter, containing the clinometer disc F (Fig. 62) and compass card G, protected, as shown, by a pierced cover. When used as a clinometer it is fixed upon the stand in position, and by means of a clamp-screw may be arranged for observation either as compass or clinometer. In the latter case the box must be fixed perfectly vertical, so as to allow the clinometer end, which is weighted, to swing freely. The telescope B is now directed towards the object required, and having cross wires, it may be clamped at the exact point of intersection. This being done, the microscope will mark the rise or fall in inches per yard on the disc, which is so compensated that its zero shows a perfectly horizontal plane. The observation may also be taken with the slot in the prism and the wire of the vane I. The price of this instrument, packed in a mahogany case, with solid leather cover and sling, also leather-bound canvas case for tripod stand, is £14 14s.

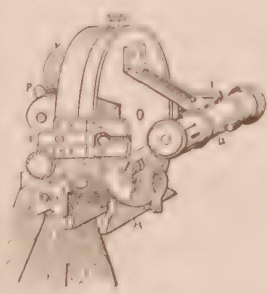


Fig. 62.

Combined Clinometer and Prismatic Compass.—A modification of the foregoing instrument, invented by Captain Barker, will be

found extremely valuable for ordinary work in the field. Being of

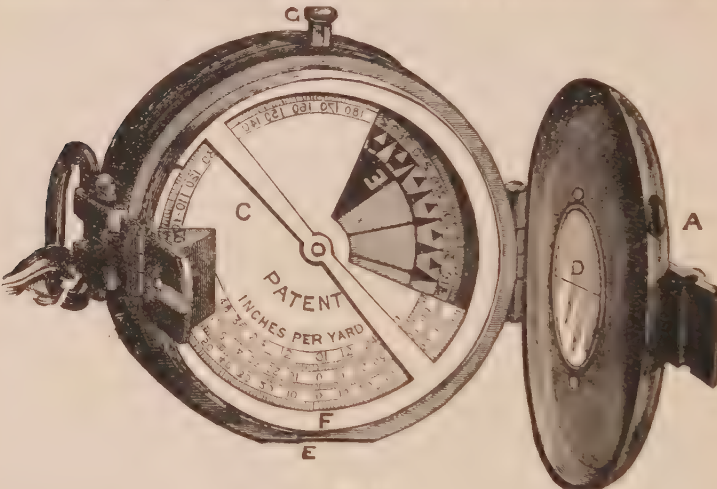


Fig. 63.

a pocket size, it is of course only a hand instrument. It has a com-

Fig. 64.

pass card E (Fig. 63) and a clinometer disc C, with the slotted prism B

and the vane D. It is illustrated in position for observing the angle of slope, but if held horizontally it can be used as a prismatic compass. When being used as a clinometer, as in Fig. 65,

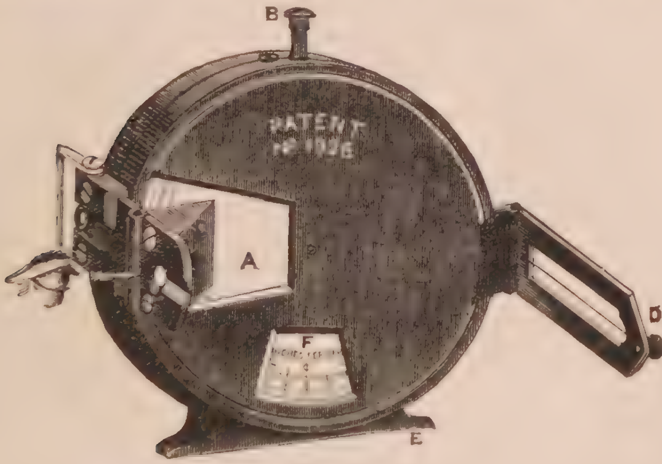


Fig. 65.

the disc A records the angle of slope by means of the prism C, whilst F is a scale of rise or fall in inches per yard corresponding with the observed angle. The disc is balanced so that zero corresponds with the horizon. When it is desired to use this instrument, as in Fig. 64, by pressing the knob B the disc revolves, so that the compass card will be revealed beneath the prism. The cost of this appliance is £4 4s.

There is another type of combination having the prismatic compass on one side and the clinometer disc on the other, in which case the sight-vane of the former folds over the compass. A shorter vane which folds back, being only the depth of the box, is used for vertical angles, and which, when not in use, also throws the clinometer disc out of gear. Fig. 66 illustrates this instrument when closed ready for being put into its case, where A is the prism folded back, B the sight-vane for the compass, and folding over it, in doing which it presses a knob which throws the card off its centre, and C is the sight-vane for the clinometer, which also folds

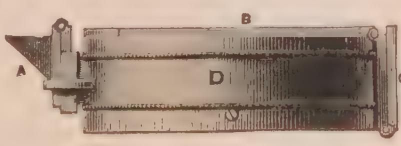


Fig. 66.

back. Fig. 67 shows the instrument open for use as a compass, and in Fig. 68, by turning the box over and reversing the prism, it may be made to serve for clinometer observations with the arm c.

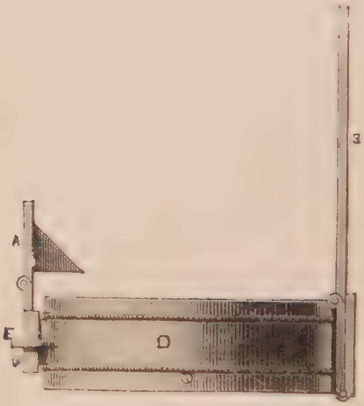


Fig. 67.

Fig. 68.

Prismatic Compass. No surveyor should be without this instrument (Figs. 69 and 70), as apart from the fact that it is

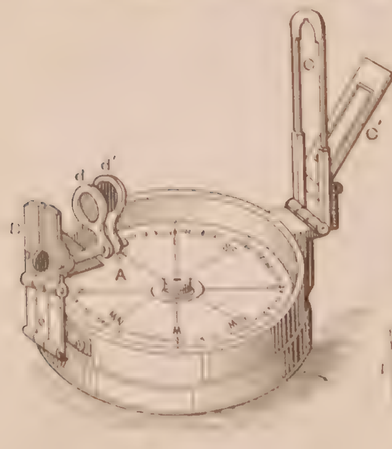


Fig. 69.

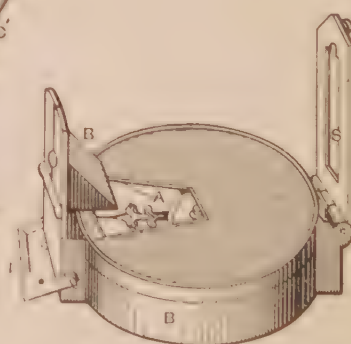


Fig. 70.

extremely useful for observing bearings, and even traversing, it is, in the absence of a theodolite, the only reliable means of determining the magnetic north in connection with a survey. It

consists of a magnetic needle balanced on an agate centre or pivot, and carrying a card A, or metal ring, divided into 360 degrees and subdivisions of one-half or one-third of a degree, according to the size and manufacture of the compass. This is contained in a brass or bronze box, from $2\frac{1}{2}$ inches diameter and upwards, at one end of which is a sight-vane C, and at the other is a magnifying prism B, enclosed in a metal case, having a slot for observation, so arranged that whilst the eye sights through the slot—towards the wire contained in the vane—the prism, by means of being silvered on its slope, reflects the reading on the card at the same time. When in use the prism is turned by a hinge over the card, and similarly the vane is fixed in a vertical position; but for portability, when not in use, the vane folds on to the glass of the compass, and in doing so it presses a knob which throws the needle off the bearing to save undue wear. Whilst the prism is turned back on to the ring of the box, and is held in position by the movable strap *b*, the whole is covered with a lid (which may be attached to the bottom during use) to protect it from injury. The better kind of compasses have a permanent metal top, with a glazed aperture over the prism for taking observations. It should be stated that a knob is arranged in the ring under the vane to enable the operator to steady the needle, by pressing the card, to avoid undue swinging. The best kind of prismatic compasses are fitted with green and red glasses as at *d d* for azimuth observations. The prismatic compass gives the bearing of a line, or in other words, the angles formed by that line and the magnetic meridian.

I have explained that the card or ring is divided into 360 deg., but whereas in ordinary cases this 360 deg. on north would point in the direction of the vane, in the case of the prismatic compass, for facility of reading the angle during observation, the order is reversed, so that the north on the card is marked 180 deg., south 360 deg., east 270 deg., and west 90 deg. By this means the 360 deg. is brought under the prism as at A in Fig. 71, so that in directing the vane towards the point from which the bearing is required, the operator is enabled to simultaneously read the angle and cut the point of observation with the vertical wire of the vane.

Fig. 71.

It should be observed that the prismatic compass cannot be used in places or under any circumstances where there is the slightest metallic attraction, as the needle is so sensitive that the least thing will cause a variation. Again, the compass must not be relied upon for extensive triangulation, as from local and other causes slight errors are certain to occur.

It has been argued that more accurate observation would be taken if, instead of holding the compass in the hand, it were attached to a tripod-stand; but I doubt whether the steadiness that is thereby assured compensates for the advantage of keeping the card or ring alive by the motion of the hand.

The Circumferentor.—This is an extremely valuable instrument (Fig. 72), being next to the theodolite in point of reliability, always excepting local or other attractions. Fixed upon a tripod-stand with a ball-and-socket arrangement, it may be placed over a station and so adjusted that the observation may be accurate.

It consists of a compass-box A, from 4 in. and upwards in diameter, which is divided into 360 deg., subdivided into minutes; over this is fixed the pivot carrying the needle (which, when not in use, should always be thrown off its point to preserve it), and attached to the outer case are the two sights C and B, with which the angle is observed. These sights, made of brass, have in each two slots and a circle. Alternating in each, the larger slot in the upper sight (B) contains a vertical wire, whilst the corresponding slot in C is only just wide enough to look through, the lower slot in C has the wire, and that in B is similar to that in C to look through. It will also be observed that at the top of B and bottom of C are what appear in the figures to be dots, which are really small holes, while at the bottom of B and top of C are circles with horizontal and vertical wires. These are, again alternately, for observing the intersection of the cross wires with an object back or front. When out of use these sights or arms, by hinges, fold over the glass, protecting the dial.

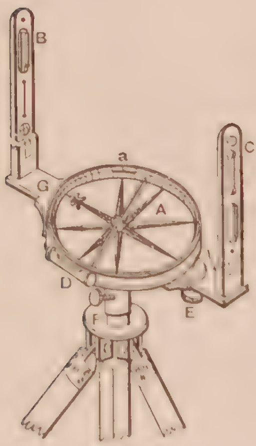


Fig. 72.

There is a spirit-level D attached to the lower part of the box for the purpose of fixing the dial perfectly horizontal, which is effected by a ball and socket arrangement. The dial has a socket, which fits on to the pivot of the tripod, and by means of a screw F the instrument can be clamped or fixed. The arms or sights and the rim of the circumferentor are turned round by the screw E, by which they may be brought into accurate line of sight. Thus, to take an observation, place the instrument directly over the station point by means of a plumb-bob attached to the apex of the

tripod; fix the two plates by the pin underneath the compass-box, and bring the sights round, so that the needle and 360 deg. coincide. Having levelled the instrument, fix it by the screw F, then release the pin, and by the screw turn the sights until they cut the points set up; the vernier on the rim will give the angle taken from the meridian.

Preliminary Adjustment of the Theodolite.—The preliminary adjustment of the theodolite is to plant the instrument accurately over the station.

Before going into the merits of each it is necessary to explain those portions which are similar in all instruments. The stand, or tripod, is usually in the form of three legs, each of which being in the section of a **V** on two sides, and in the form of an arc on the other (as in Fig. 73), when not in use, they may be closed for convenience of transit. These legs are shod with an iron spike to facilitate their being firmly held in the ground, whilst at the top is a segmental plate carrying the legs which fit into two corresponding legs in the stock, thus forming a hinged joint. This joint is generally formed by a large surface-bearing pin, which is tapped at the end to receive a slot-headed tightening screw. In spite of excellence of manufacture, this joint is found to be a constant source of trouble from the fact that in process of time its screw gets loose, and the steadiness of the instrument is impaired; but by a very ingenious and valuable arrangement Messrs. Troughton and Simms have substituted a double lug on the legs and one of extra thickness on the stock, and instead of the slot headed tightening screw the joint is formed by means of a bolt and nut, to tighten which the cap-piece has its upper portion made in the form of a box spanner. For ordinary purposes, equally as in levelling, this form of tripod-stand is the best and most convenient; while for special work there can be no doubt that the framed stand—similar to those used for cameras, but more elaborate—is the best, for reasons which will be explained presently.

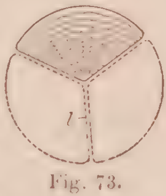


Fig. 73.

Adjusting the Vertical Axis.—This is done by means of a plumb-bob suspended from a small hook held in the centre of the stock-head. It requires the greatest care and patience to do this, as much depends upon the manner in which the tripod has been fixed. Approximately, bring the plumb-bob over the nail or cross-cut of the station, and gently pressing each leg into the ground, one by one, the point of the bob may be made coincident with the centre of the station, as is illustrated by Fig. 74. The cord carrying the plumb-bob should be strong, and as the distance from

the stock-head to the ground is constantly varying according to

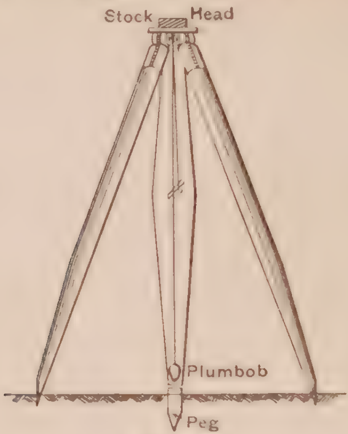


Fig. 74.

circumstances, it should be elongated or shortened by means of a runner.

Centering Plates.—There have been several improvements in the theodolite with a view to greater accuracy in adjusting the

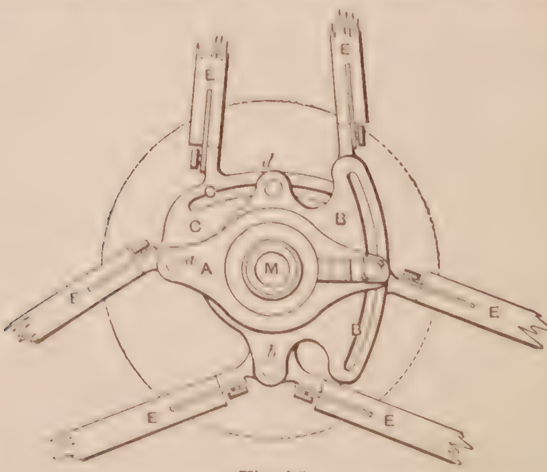


Fig. 75.

vertical axis of the instrument over a station, by means of centering-stands, whereby the plumb-bob may be adjusted to a nicety. One

of these arrangements, by Messrs. Troughton and Simms, is illustrated in Figs. 75 and 76, and is only applicable to the framed stand. It consists of three plates, A, B, and C, which work one upon the other as follows: the plate A, to which the theodolite is attached, works upon a pivot at *a*, fixed to the underneath plate B, by which means the pin *c* (having a clamping arrangement)

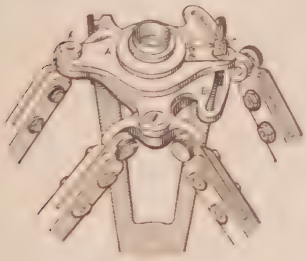


Fig. 76.

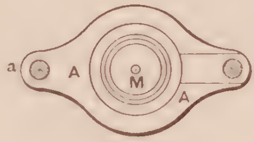


Fig. 77

may work in the segmental slot E′. The middle plate B, to which A is pivoted, also works on a pivot in C at *b*, and traverses the segmental slot *c*′, and can therein be clamped by the thumbscrew *d* underneath the plate, so that the upper plate A can be made to traverse in all directions a space of about 3 in., thus admitting of the plumb-bob being adjusted to a hair's breadth. Figs. 77 (A), 78 (B), 79 (C) are sketches of each plate separately

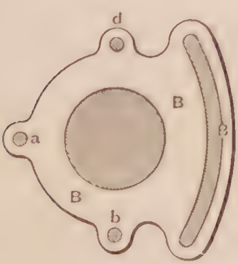


Fig. 78.

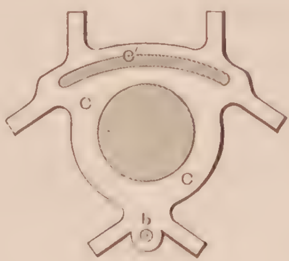


Fig. 79.

in relative positions, the plumb-bob being held by a hook at M (Figs. 75 and 77), and attached to the plate A.

A modification of this arrangement has been devised by the same eminent firm, adapted to the ordinary tripod-stand, and is illustrated by the sketches in Figs. 80, 81, 82, whereby two plates, one upon the other, are made to take any lateral movement to the extent of about an inch by the ingenious method of making the

upper plate move in a double slot J J (Fig. 81), at right angles to slots K K in the underneath plate, so that a loose pin L (Fig. 82) enables one plate to revolve upon the other of nearly the length of the slot. The plate D (Fig. 80) is made to screw on to the box C,

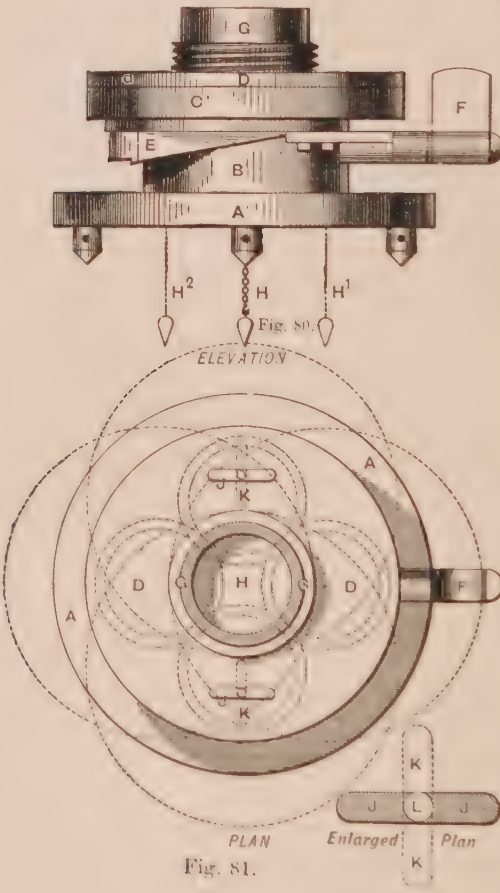


Fig. 80.

Fig. 81.

Fig. 82.

and is held firm by a screw *d*. The instrument may be thus moved in any position to adjust its vertical axis over a station, and when accomplished, the centering-plates may be firmly secured by means of the clamp-screw F, which is connected with the wedge E, and by drawing it inwards jambs the two plates so that they cannot move.

The possible movement of the centering-plate is illustrated by the dotted circles in Fig. 81, and the range of movement of the plumb-bob is shown by the dotted lines H^1 and H^2, Fig. 80. It should also be stated that the sketch shows an arrangement for utilising this contrivance as a wall-stand, the lower plate A (Fig. 80) having four spikes provided for that purpose, or having a female screw within, A and B. It can be screwed on to the tripod-head.

Above the joints of the stock-head is the screw upon which the instrument is held; and when not in use this screw is protected

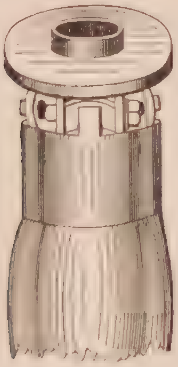


Fig. 83.

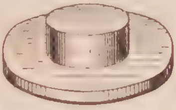


Fig. 84.

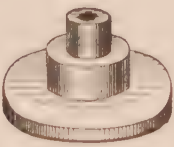


Fig. 85.

by a hat-shaped cap, but which has recently been improved by having a box spanner attached. Fig. 83 shows the stock-head complete, Fig. 84 is the ordinary cap, and Fig. 85 is the improved cap and spanner.

We now come to the instrument proper, which consists of three parts: the parallel plates, the horizontal and the vertical limbs.

Parallel Plates.—The parallel plates are illustrated in Figs. 86 and 87, and consist of two circular plates, kept a certain distance

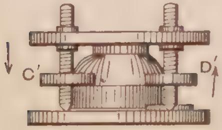


Fig. 86.

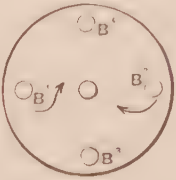


Fig. 87.

apart by a ball-and-socket (which forms part of the upper portion of the instrument), and four screws, B^1, B^2, B^3, B^4, placed at right

angles to each other, and called the parallel screws. The upper plate is pierced with four holes, which are tapped with a female screw, in which a screw having in its centre a milled head works, but whose lower extremity rests and works upon the lower plate; and in order to prevent the upper plate revolving there is a **U**-shaped guard round one of the screws.

Parallel Plate Screws.—The action of the parallel plates is regulated by screwing and unscrewing each pair of opposite screws. Thus, if the right end of the plate, as D^2, Fig. 86, is required to be raised, then the left end C^1 must be depressed, which is effected simultaneously by turning the screws B^2 and B^1, Fig. 87, inwards, whereby B^2 is elongated and B^1 shortened. If, on the other hand, it is desired to elevate at C^1 and depress at D^2, then these screws must be turned outwards, whereby B^1 is elongated and B^2 shortened. Similarly, B^3 and B^4 have to be dealt with. Fig. 88 illustrates how the screws are manipulated.

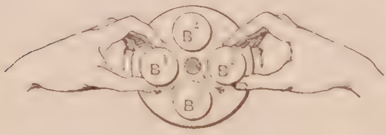


Fig. 88.

Ball and Socket Arrangement.—Referring to the ball-and-socket arrangement, it is necessary here to explain that it forms one of the most important parts of the theodolite. The lower parallel plate has a dome shaped socket very accurately turned to receive the semi-spherical lower portion of the body-piece. The upper parallel plate has also a socket, upon which rests the shoulder of the body piece; thus the four parallel screws serve to keep the upper and lower plates apart; and according to the elongation or shortening of each pair, so the ball-and-socket arrangement admits the elevation or depression of the upper plate as required. The object of this is to maintain the instrument in a truly horizontal position, as will be presently explained; but having by means of the four screws adjusted it level, it is necessary that they should all firmly bite the lower plate, *but not too much so*, otherwise the threads of the screws will be injured, and indentations will appear on the plate.

Now the body piece before referred to is hollow, but its interior is in the form of an inverted cone, within which works a solid spindle of similar shape, both being so accurately ground to fit that the axes of the two cones may be parallel.

The Limb or Lower Plate.—The body-piece supports a circular plate (whose diameter distinguishes the particular size of the instrument), called the lower plate or limb. This plate is bevelled to an angle of about 60 deg., and has besides a graduated

scale (called the primary scale) divided into 360 deg. and subdivisions, marked upon silver. This scale reads continuously from

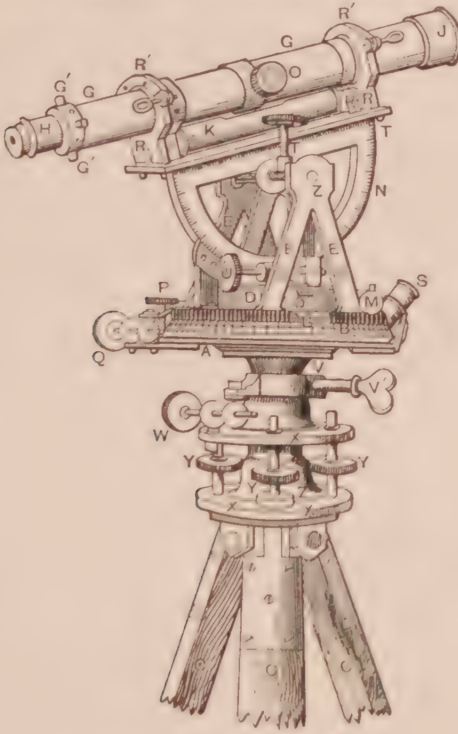


Fig. 89.

right to left. Fig. 89 is an elevation of an ordinary **V** theodolite, and shows the limb A and also on the plan (Fig. 90).

The Upper or Vernier Plate.—Working upon the limb, supported by the internal cone or vertical axis, is another circular plate of less diameter (by the width of the chamfered edge), called the vernier plate, B, which, unlike the limb, is only bevelled in two places, 180 deg. apart. At these two points, L L, Fig. 90, are what are called the verniers, for the purpose of minutely reading the subdivisions of the primary scale. Now the vernier plate is so constructed that it will freely move upon the limb, being held thereto by a washer and set-screw passing through the lower portion of the body-piece into the vertical axis of the vernier plate, so that, unless prevented, both plates can work con-

centrically, one upon the other, and the lower one upon the socket of the upper parallel plate. But for the purpose of taking an

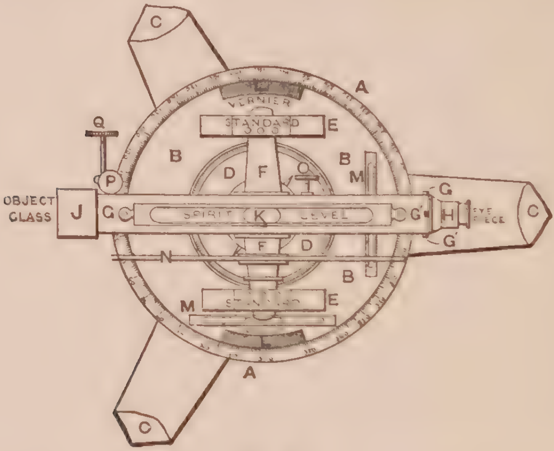


Fig. 90.

angle, it is necessary to fasten each plate according to their relative positions.

Clamps.—It will be noticed in Fig. 89 that, underneath the limb, there is a loose collar marked v, terminating in two lugs, through which a screw v′ passes, which being tightened (Fig. 91) clutches round the body-piece and holds it tightly. This is called the clamping arrangement, as v′ is the clamp-screw.

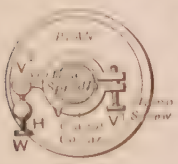


Fig. 91.

Tangent or Slow-motion Screw.—Now we have seen that this body-piece only rests upon and works in the socket of the upper parallel plate, and the mere fact of clamping it, unless it were prevented from moving on this plate, would be of no avail. Thus a bracket, also attached to the collar, is connected with a sphere moving on a pivot from the bracket, and pierced to receive a screw w (Fig. 89), which also pierces a sphere and works tangentially to the vertical axis. This last sphere revolves on a spindle attached to the upper parallel plate. By this means a gradual motion is imparted to the limb, which admits of the most accurate adjustment. This latter arrangement is called the tangent or slow-motion movement, and the screw w is the tangent-screw. For the purpose of fixing and regulating the vernier-plate there is a clamping arrangement P (Figs. 89 and 90) which clutches the upper

plate to the limb, whilst a gradual motion of the upper upon the lower plate is effected by means of the slow-motion screw Q, which works tangentially through pierced spheres attached equally to the one and the other.

The foregoing is a brief description of the ordinary clamping and slow-motion process in nearly all theodolites.

Troughton's Clamp and Tangent Arrangement.—It is necessary, however, to mention that a very considerable improvement in this system has been introduced by Messrs. Troughton and Simms, and by their courtesy I am able to give an illustration in Fig. 92. The vertical axis A works within a collar B, having two arms. This collar has a segmental recess on the left side to secure the axis when pressed by the tumbling-piece C, which is actuated by the clamp-screw D. The slow motion is imparted by means of the spring F on the one side and the tangent-screw G on the other, and pressing against a lug E fastened to the plate below, so that as the screw is turned the spring recedes or follows it, and the most minute movement may thus be effected. It occurred to me that this spring might in time lose its power, but the makers assure me that with ordinary fair usage this is not likely to happen. Such being so, there can be no doubt that it is an improvement upon the other method.

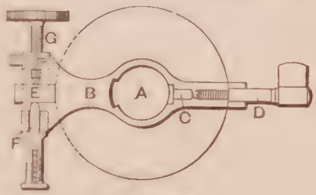


Fig. 92.

Levelling the Plates.—I have spoken about the necessity of having the instrument perfectly horizontal, to ensure which, there are placed upon the vernier plate, at right angles to each other, two spirit-levels (J and K, Fig. 93), each of which is parallel to one pair of screws, thus: J with B^1 and B^2, and K with B^3 and B^4; and by the manipulation of these screws the bubbles of J and K should be brought exactly to the centre of their run; and this being so, if the instrument is in good order and adjustment, then the vernier plate and limb are parallel with the horizon. This is one of the most important matters to be attended to, as unless the instrument is perfectly level the value of the observation is impaired.

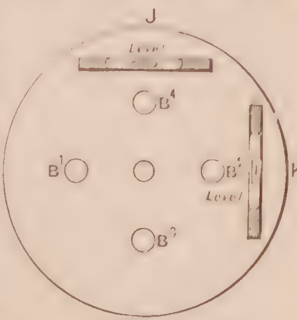


Fig. 93.

Vertical Arc.—Proceeding with the consideration of the component parts of the theodolite, we now come to the vertical arc or circle, which in the former case consists of a semicircle of metal, divided on one side each way from 0 deg. to 90 deg., and subdivisions, whilst the other side is divided to show the hypotenusal allowance in links per chain. Connected with this semicircle are trunnions, which work in journals in the head of the bearers or "A" frames E E (Figs. 89, 90, and 94); and on the top is a strong bar, carrying the supports or Y's, R′ R′, in which rests the telescope. It is from these supports, from their resemblance to the letter Y, that this particular type of instrument is so called. The telescope G is held in the Y's (Fig. 95) by clips, working upon a hinge on one side, and fastened on the other by a pin passing through eyes in

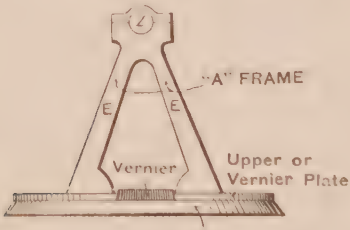


Fig. 94.


Fig. 95.

the jaw of the Y and the clip. This arrangement has been superseded in the most modern theodolite by a spring, which prevents any possibility of the telescope falling out of the supports by neglecting to fasten the pin in the clips.

Compass. Beneath the telescope and between the "A" frames a compass box D is fixed upon the vernier plate, containing a silver ring, graduated from 0 deg. to 360 deg. The needle is supported upon an agate centre, and has a lever connected with it, by which, when not in use, it may be thrown off its centre, and thus save undue wear. Attached to the compass box is a vernier for reading the minute subdivisions on the vertical arc, which is clamped by the screw T on the top of the "A" frame, whilst slow motion is effected by the tangent screw U. (Fig. 89).

Telescope.—The telescope G consists of two tubes, one sliding within the other. The outer tube has at its further end J (Fig. 96) the "object-glass," which forms at its focus an inverted image of the object looked at. This is protected by a sliding cylinder J, which pulls out to shield the object glass from the sun and weather, at the end of which is a movable disc to close it up when not in use (see sketch, Fig. 97). The inner tube has at its nearer end

H a combination of glasses called the eye-piece, which magnifies the inverted image. By moving the inner tube inwards and out-

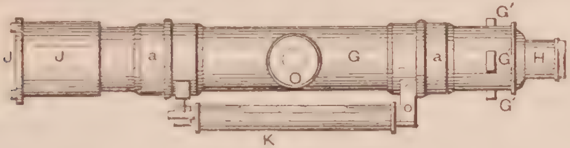


Fig. 96.

wards, with the rack and pinion contained within it, the milled-head O working a screw through a collar on the larger tube, the foci of the object-glass and eye piece are adjusted till they coincide, which is known by the distinct and steady appearance of the image. Upon the outer tube are also collars *a a*, very accurately turned, to fit into the Y's of the "A" frame.

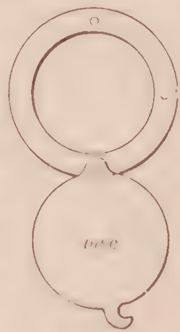


Fig. 97.

The Diaphragm.—At the common focus of the object-glass and eye-piece where the inverted image is seen is the diaphragm or partition at *G′ G′ G′*. The diaphragm consists of a ring of metal (Fig. 98) held within the telescope by means of four capstan screws placed at right angles to each other. The screws work easily through holes in the telescope, but the threads actuate the diaphragm ring, so that it may be brought vertically or horizontally nearer the sides of the telescope, by screwing or unscrewing. Across this diaphragm or partition are usually three spider's webs, or equally very fine platinum wires (see Fig. 99), one horizontal, A B, and the other two, C D, E F,

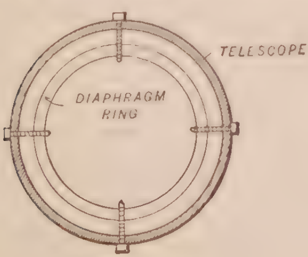


Fig. 98.

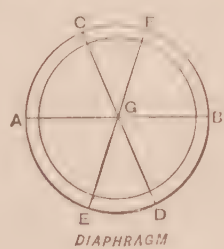


Fig. 99.

deviating slightly to opposite sides of a vertical plane. The point G, where these wires intersect, should be exactly in the axis of

line of collimation of the telescope. In some theodolites there are only two wires, one vertical and the other horizontal.

Attached to the telescope underneath (in some cases above) is a spirit-level K (Fig. 96), which by screws may be set exactly parallel to the line of collimation ; so that when the air bubble is in the centre of the level the telescope is horizontal.

The Vernier.—The vernier, in its ordinary sense, is a contrivance wherewith the intervals between the divisions on the primary scale may be accurately measured. It is a scale whose length is generally one less than a certain number on the primary scale, so that, supposing the lower plate is divided into degrees and half-degrees, if we take 29 of the subdivisions (or 14 deg. 30 min.*) and divide this length into one more or less parts than those of the primary scale, whose length regulates that of the vernier, we shall have a means of determining the actual number of minutes which intervene between the subdivisions.

It is customary to divide the vernier into thirty equal parts, so that it has thirty spaces to the twenty-nine subdivisions on the limb.

For greater minuteness of observation some modern theodolites are divided into thirds and fourths as well as into half degrees, in which cases the verniers are divided into twenty and fifteen parts respectively, so as to accurately record the intervals between the subdivisions.

In consequence of the limb and vernier being circular in shape, it is found more easy to illustrate the relationship of the latter to the former by straight line, and Figs. 100, 101, 102 will serve to do so.

Fig. 100 shows a portion of the primary scale drawn straight from 45 deg. to 72 deg., and from 50 deg. to 64 deg. 30 min. I have marked the 29 half-degrees as the length of the vernier. Now, taking this length and dividing it afresh into thirty equal parts, it will be seen by Fig. 101 that, whereas the vernier scale commences at 50 deg. and terminates exactly at 64 deg. 30 min., so that the commencement and termination are coincident with the division 50 deg. and 64 deg. 30 min. on the lower scale, yet not one of the divisions of the vernier intermediate between its commencement and termination will cut any one of the points in the lower scale between 50 deg. and 64 deg. 30 min. If the student can once grasp this fact, then the difficulty of the vernier is simplified.

Now, if the foregoing argument be proven, it is easy to understand that once the vernier moves from 50 deg. it is possible for

* The degree is shown by a circle thus "°," minutes by one dash thus "′," and seconds by two dashes, thus "″."

any *one* of its divisions to intersect any one of the divisions and subdivisions of the lower scale, but only *one* at a time.

As an illustration, the first division of the vernier may be in line with 50 deg. 30 min., and such being the case, the other twenty-nine divisions would not be coincident. This then would show the angle to be 50 deg. 1 min. Again, the tenth division

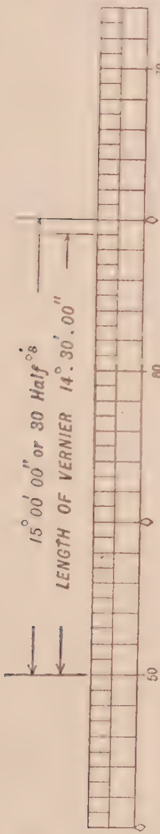


Fig. 100.

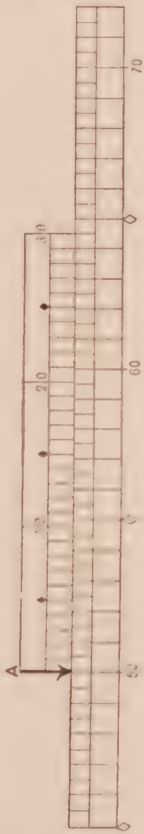


Fig. 101.

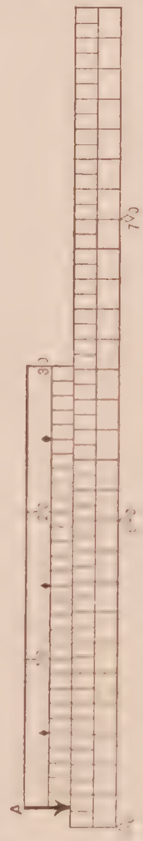


Fig. 102.

may be coincident with 45 deg. This shows that ten minutes more than the 50 deg. or commencement have been recorded, in other words, 50 deg. 10 min. Further, if the twentieth division or the upper scale is coincident with any division or subdivision on the lower one, it must of necessity be at 60 deg., consequently the reading of the vernier is 50 deg. 20 min. And lastly, if the thirtieth division or end of the upper scale is coincident with one

of the divisions or subdivisions of the lower one, it must be at 65 deg., and thus, thirty of the divisions in the upper scale having traversed from left to right, the arrow A (Fig. 101) will be coincident with the subdivisions between 50 deg. and 51 deg., or at 50 deg. 30 min. So we see, that even if each of the thirty divisions of the upper scale are consecutively coincident with any division or subdivision of the lower one, at the end we have only moved one half degree in a direction towards the right.

Now, supposing it is discovered by aid of the microscope that the arrow A (Fig. 102) has passed 50 deg. 30 min., common sense will tell that the first half-degree in the lower plate has been passed, and it is desired to ascertain how many of the minutes in the second half-degree are recorded by the vernier.

In this case (Fig. 102) it will be seen that the seventh division of the upper scale is coincident with 54 deg., and seeing that the arrow A has passed the first half-degree beyond 50 deg., then the reading will be 50 deg. 30 min. + 7 sec. = 50 deg. 37 min., and supposing the thirtieth division of the vernier was coincident with any in the lower scale, it must be that at 65 deg. 30 min. when the arrow A will have reached the full length of the first degree past 50 deg. or 51 deg.

At the risk of being thought verbose upon this subject, I have endeavoured to make the vernier appear as clear as possible. The foregoing remarks apply to those theodolites whose limbs are only divided into degrees and half-degrees; but in the larger instruments the degrees are divided into third parts of twenty minutes each. "Suppose, for example, the limb is so divided, and that it is to be subdivided by a vernier to third parts of a degree or 20 min., each subdivision being one-sixtieth part of the primary division, the length of the vernier will be 60 — 1 = 59 divisions of the primary scale; and it will be divided into sixty equal parts, each equal to 59 60ths of a division of the primary scale." To make this more simple, if we take twenty of the divisions and subdivisions of the lower scale and deduct one from that length, then by dividing this length of nineteen parts of the lower scale into twenty we shall have a vernier which will exceed each single minute of the first third of a degree, as each one becomes coincident with one of the divisions or subdivisions of the primary scale.

The cost of "Y" theodolites is as follows: four-inch, £21; five-inch, £25; six-inch £30.

Transit Theodolite.—This (Fig. 103) is unquestionably a more reliable instrument than the cradle (Fig. 89), although objections against it have been raised, principally on account of the increased height of the standards. I can only say that I would never use any other where accuracy and facility of work are important. One of its greatest advantages is that by reason of the standards

being made higher, the telescope is free to revolve on its axis, and we thus save the troublesome work of taking it out of the Y's, as is the case with the cradle, so that in prolonging a line from A to B (the instrument being at B) on to D it is only necessary to turn the telescope over, and, providing the instrument is in adjustment, you obtain a more accurate result in much less time. The transit, so far as the clamping and slow-motion screws of the lower and upper plates and the vertical circle (not an arc or semicircle), is similar to the cradle theodolite. The vertical circle, like the horizontal limb, is

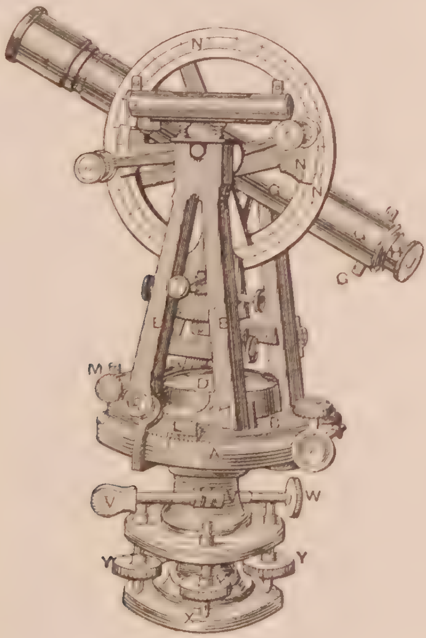


Fig. 103.

divided into 360 degrees and subdivisions, and has two microscopes in length of its diameter, which revolve round the horizontal axis. For special purposes it is fitted with a supplementary level X (Fig. 104) fixed by standards with jaws on to the horizontal spindle, this being an additional safeguard against the upper portion of the instrument being out of the horizontal. The larger instruments, such as are chiefly used in constructive works, are fitted with a small spirit lantern, resting on a bracket attached to one of the A frames. This is to throw rays of light into the telescope, through a crystal let into the arc, when observations are required to be

taken in the dark. My own experience has been that such appendages are more trouble than they are worth, and the extra money would be better spent upon strengthening the working parts of the instrument. If it is required to work in the dark you can have a

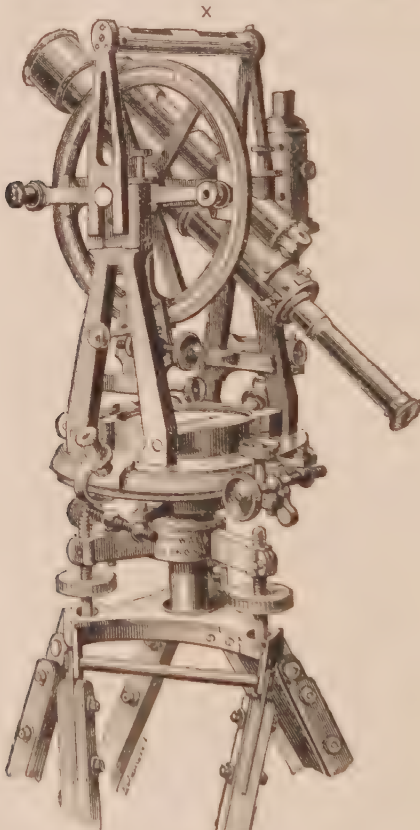


Fig. 104.

man with a lamp against the instrument, which answers the same and a better purpose, for if you are taking angles you can also use this lamp to read the vernier.

Triangular Plate.—Figs. 104 and 105 show the tripod to be surmounted by a triangular plate, in which only three levelling screws are used, the parallel plates being dispensed with. The lower part of the screw has a shoulder which fits into a pear-

shaped hollow slot. The advantage claimed for this method is that the instrument can be levelled with one hand only, whereas with four screws both hands are required. But I must confess I

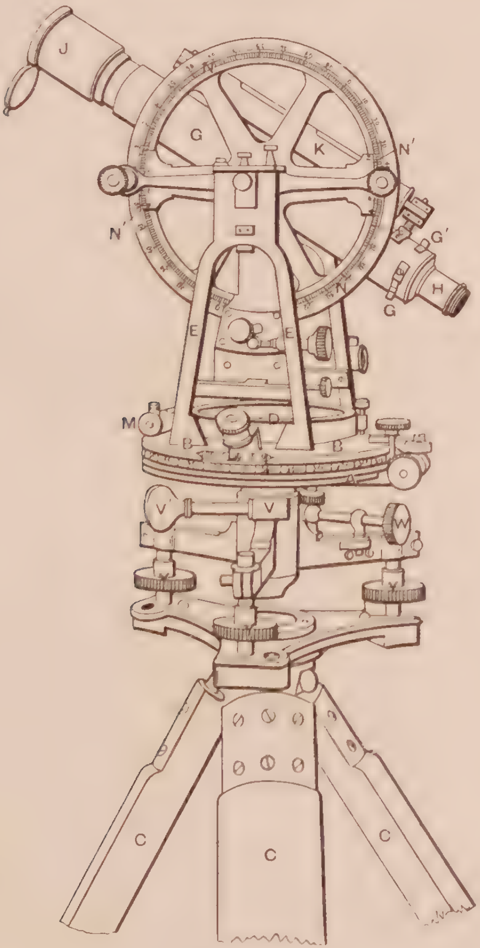


Fig. 105.

have a strong prejudice in favour of the old system, and most transit theodolites are made with parallel plates and four screws.

The cost of transit theodolites is as follows: three-inch, £23;

four-inch, £26; five-inch, £28; six-inch, £32; seven-inch, £40; eight-inch, £58; and ten-inch, £125.

Everest Theodolite.—So called after the name of its designer, the late Sir George Everest, of the Indian Trigonometrical Survey. The chief efficacy of this beautiful instrument (Figs. 106 and 107) is that the limb may be made of much greater diameter, and consequently there is scope for greater detail in the working parts and a more powerful telescope.

There is only one horizontal plate divided into 360 deg., and instead of an upper plate three arms radiate from the vertical axis,

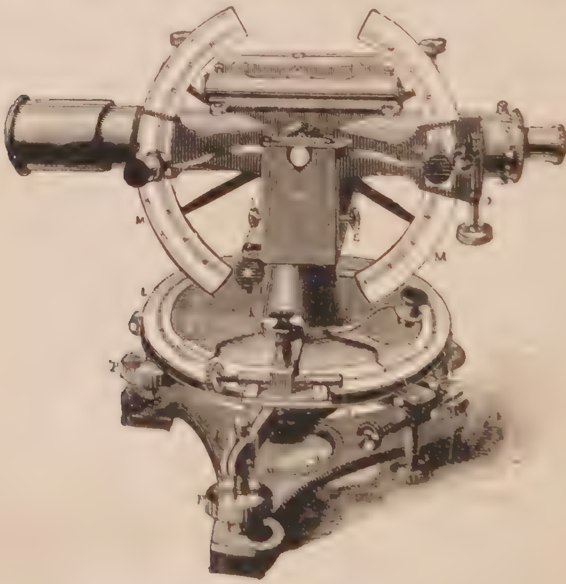


Fig. 106.

thus Y Y being the verniers and the arm which clamps this arrangement to the limb *a*, having also a slow-motion or tangent screw with which to manipulate it. The standard is much stronger than in other theodolites, and, whilst the telescope is mounted somewhat in the same manner as the transit, yet it cannot revolve upon its axis. Instead of having a vertical circle the Everest has two arcs, M M, with an arm fixed to the telescope, using the same axis, and consequently travelling with it, at either end of which are the verniers.

The Everest, so far as the arrangement for levelling is concerned,

is similar to that already described, having only three screws, and no ball and socket, and when not required to be used upon a

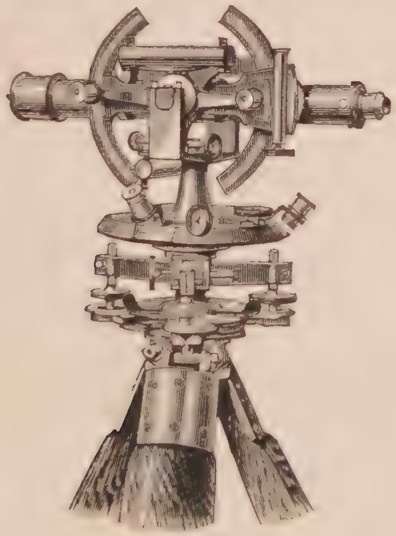


Fig. 107.

tripod is so constructed that it may rest upon a wall or any flat surface.

The cost of an Everest theodolite is as follows, including case and tripod-stand: 4-inch, £21; 5 inch, £25; 6-inch, £28; 7-inch, £34; 8-inch, £39; and 10-inch, £54.

Box Sextant.—This is an instrument, without which no surveyor should go into the field. It may be made to serve the purpose of an optical square. I have had an opportunity of testing its merits, as some years ago I had to make a survey of a large portion of the town of Sunderland for Parliamentary purposes, and for a length of seven miles, when a theodolite would have been impossible in consequence of the heavy traffic in the principal streets. I found this little instrument invaluable, and the results highly satisfactory.

The box sextant is about 3 in. in diameter and 1½ in. deep, and has a lid which completely covers it when not in use, but which can be screwed on to the bottom, and serves as a handle when taking observations. Fig. 108 is a view showing the chief features of the instrument, and also gives a fair idea of its internal arrangements. A graduated scale F from 0 deg. to 140 deg. with subdivisions, is engraved on a silver arc, and along this moves the

vernier attached to the index arm E, to which is fixed a mirror C. This arm is moved by the milled head screw acting upon a rack and pinion within the box. In the line of sight, but fixed, is another mirror called the horizon glass D, the upper part of which only is

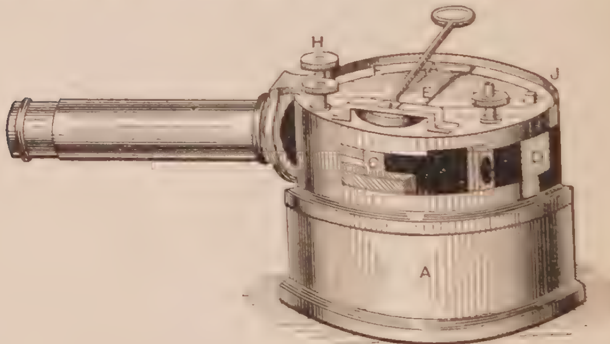


Fig. 108.

silvered, the lower and transparent portion being opposite the opening. This glass is fixed perpendicular to the plane of the instrument. These two mirrors, when the vernier is adjusted to zero, should be parallel.

There are two levers connected with coloured glasses, which may be interposed when solar observations are taken, but when not required can be depressed into the box. Many sextants are provided with a telescope, which can either fit into a socket within the instrument, and pulled out when wanted, or attached at the top by means of a screw, as H in Fig. 108. But for general use the naked eye is quite sufficient, under which circumstances a segmental plate with a hole pierced in the direct line of vision is made to take the place of the telescope aperture by slide.

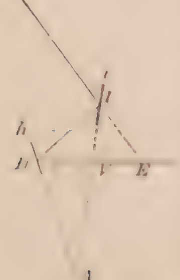


Fig. 109.

The principle upon which the sextant acts is as follows: "When a ray of light, proceeding in a plane at right angles to each of the two plane mirrors, which are inclined to each other at any angle whatever, is successively reflected at the plane surfaces of each of the mirrors, the total deviation of the ray is double the angle of inclination of the mirrors." For, let I *i* and H *h* (Fig. 109) represent sections of the two mirrors made by the plane of incidence at right angles to each of them, and let S I represent the course of the

incident ray, then the ray S I is reflected into the direction I H, making with I *i* the angle H I A equal to the angle S I *i*, and is again reflected at H into the direction H E, making the angle E H A equal to the angle I H *h*. Now the angle A H V being equal to the exterior angle I H *h* is also equal to the two interior angles H I A and H A I; and because the angles A V H and I V E are equal, and that the three angles of every triangle are equal to two right angles, therefore the two angles V I E and S E H are together equal to the two angles A H V and H A I, and therefore the angle H I A, and

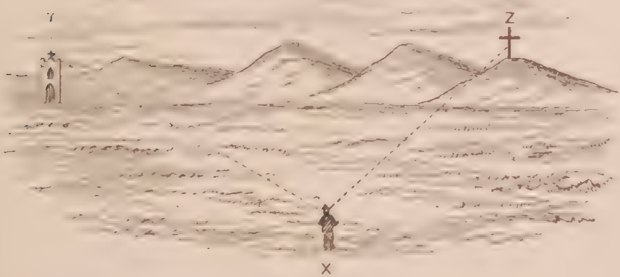


Fig. 110.

twice the angle H A I (since A H V has been proved to be equal to H I A and H A I); but V I E, being equal to the vertical angle S I *i*, is also equal to the angle H I A, therefore taking away these equals the remainder of the angle S E H is equal to the remainder, twice the angle H A I.—Q.E.D.

To use the sextant, it should be held up to the eye by the right hand, so that (Fig. 110) the line of sight is in the direction of the tower, the operator standing exactly over the station X, and the vertical axis of the instrument is directly over its centre. With the left hand the milled-headed screw is manipulated so that the index mirror, being gradually turned in the direction of Z, shall reflect the image of the cross at this point, so that its centre is coincident with that of the tower Y, as in Figs. 111. Thus the vernier will record the number of degrees and subdivisions contained in the angle Y X Z.

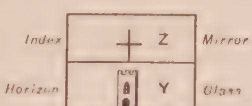


Fig. 111.

If the instrument, having been set at zero, does not show the object to which it may be directed to be exactly in the same vertical plane with the horizon and index glasses, it must be adjusted by a key being applied to the key-hole at J and turned right or left until the reflected images coincide exactly.

The necessary rules to be observed with the adjustment of the sextant are :—

1st. That the two mirrors are parallel to each other when the zero of the vernier coincides with that of the graduated arc.

2nd. That the horizon glass is perpendicular to the plane of the instrument.

To correct this latter (*i.e.* the perpendicularity of the horizon glass to the plane of the instrument), it is necessary to observe whether the reflected and the direct images of the distant horizon appear as *one*. If two horizons appear we apply the key at L and

Fig. 112.

Fig. 113.

turn it until they agree. Figs. 112 and 113 illustrate the manner in which this instrument is held and manipulated when taking an observation.

The cost of a box sextant, with telescope and large mirror and sunshades, complete in a sling case, is from £3 15s. to £5 5s.

Hughes's Improved Double Sextant.—This is an instrument which for some reasons may be said to almost supersede the box-sextant, having the advantage of measuring angles nearly double the arc which can be measured by the ordinary sextant. It consists of a five-inch or six-inch circle, with two index glasses mounted in the centre on two index arms with verniers, one measuring the angle to the right and the other to the left. The horizon glass is silvered top and bottom, with a narrow slit in the centre. The centre object is observed with a telescope through this, and the other two objects, to the right and left respectively, reflected by the index glasses into the silvered portions of the horizon glass; the three objects being in contact, the observed angles are read off with the verniers. The adjustments of the index and horizon glasses are made in the regular manner, the upper index glass being adjusted last.

This instrument, as is shown by the accompanying sketch, has a handle by which it is held in the right hand, whilst the index arms

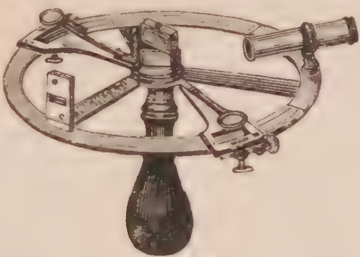


Fig 113A.

are manipulated with the left. It may also be made to fit on to a tripod-stand, similar to that described for the clinometer.

The price of the five-inch sextant, complete in mahogany box, with two telescopes, is £5 10s., and the six-inch is £6 10s.

Plane Table.—This consists of a drawing board A (Fig. 114), (usually framed, A', with a movable panel), having a sheet of drawing paper strained on it, mounted on a portable three-legged stand B, and capable of turning about a vertical axis, and of being

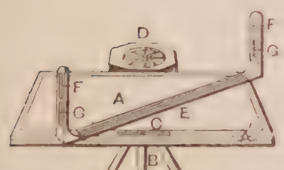
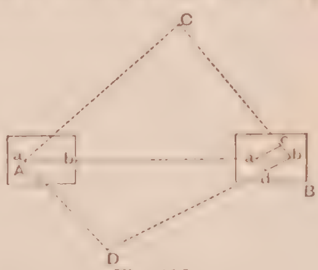


Fig. 114.



Fig, 115.

adjusted by screws to a horizontal position, as indicated by a spirit-level c being attached to the frame. The vertical axis has a clamp and tangent screw to adjust it to any required position. The index E is a flat, straight-edged ruler, having upright sights at its end. These sights have slots (F F G G) similar to those in a prismatic compass or circumferenter.

The use of the plane table resembles trigonometrical surveying on a small scale, except that the angles, instead of being read off on a horizontal circle and then plotted, are at once laid down on the paper in the field.

Fig. 115 is a simple illustration of the use of the plane table in the field. It is required to make a survey of the trapesium A C B D. Having set up rods at C B and D, the surveyor plants his table at A

and brings the north point of his compass (360 deg.) directly under the needle when at rest, and makes a point (with a needle or pricker) on some convenient part of his plane table paper to represent his station in the field. To this point he brings the fiducial* edge of his brass rule, and directs it forwards until, through the slots F F or G G (Fig. 114) he intersects with the vertical wire the rod at B. The rule lying in this direction, he draws a point pencil line.† He now proceeds to chain the line A B, and having determined its length, with a scale he proceeds to work off the exact length on the paper. The rule is now directed towards C and D, and in like manner the distances are measured on the ground and plotted on the paper, so that we have the relative positions and length of the lines A B, A C, and A D. The table is now moved to B and adjusted as before, care being taken to check the line A B in reference to the position of the table at B by directing the index-rule back upon A. Now proceed to direct the rule towards C and D, and measure the lines B C, B D upon the ground, and having plotted them with the scale we have now completed the survey, and the accuracy of the work will be proved if the length B C, B D are found by measurement to exactly coincide with the points C and D formed by measuring the lines A B, A C, and A D.

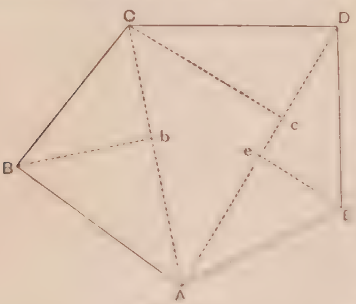


Fig. 116.

Whilst upon this subject, it may be well to mention that the plane table will be found to be very useful for ascertaining the area of the ground one is measuring. For example, suppose we have the irregular figure A B C D E (Fig. 116), and it is required to find its superficial contents. Plant the plane table at A and direct the index rule to B, C, D, and E, measure on the ground and plot on the paper the length A B = 665, A C = 885, A D = 1030, and A E = 580, and make a correct plan of the ground. Now, if you erect perpendiculars B b = 424, C c = 595, and E e = 285, there will be by the well-known rule

$$\frac{A\,C \times b\,B}{2} = \frac{885 \times 424}{2} = 187{,}620 \text{ sq. links.}$$

and

$$\frac{A\,D \times (c\,c + e\,E)}{2} = \frac{1030 \times (565 + 585)}{2} = \frac{437{,}750}{625{,}370} \text{ sq. links}$$

= 6 acres, 1 rood, and 5 perches, the contents of the field.

* The "fiducial" is the reliable or accurate edge of the rule.

† An H H H pencil is best for this purpose.

The price of a plane table, with compass, level-sighted straight-edge, and stand complete, is about £8 8s.

Telemeter.—This is an exceedingly clever little instrument, invented by Labbez, and is designed to give, without any calculation whatever, the distance of objects from 250 to 3,000 yards. It is most simple in construction, easily understood, very accurate, and not likely to get out of order. The chief merits claimed for it are, that it does not require much training to use it, nor is it necessary that an absolute right angle be laid out, and it is not dependent on seeing a definite-sized object (such as a man standing erect). Fig. 117 is a *full-size* illustration of this little instrument, and Fig. 118 is a sketch showing the method of using it. The following are the directions for using the instrument :—

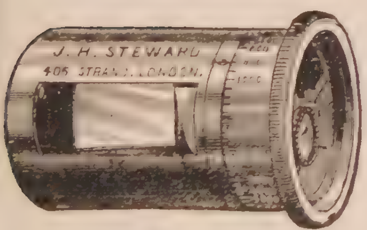


Fig. 117.

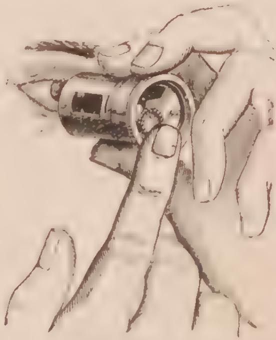


Fig. 118.

1. Open the slide at end of cylinder.

2. Set the small toothed wheel so that the zero is opposite zero-line, also set the revolving part of the cylinder so that the zero on it is exactly on the zero-line of fixed portion of cylinder.

3. To find the distance of A (Fig. 119), stand at D, face to the left, C, and notice an object (say B) of a prominent nature (known hereafter as the mark) as near as possible at right angles to the object A of which the range is required. Hold the instrument with the thumb and finger of the left hand, as shown at Fig. 118, in such a way that the oblong opening is quite free, and place it to the eye; look through the hole at the small end of the instrument at mark B, and with the forefinger of the right hand turn the small toothed wheel until coincidence between the range object A and the mark B is obtained—in other words, A is reflected on B.

4. Fasten the end of the line into the ground at D by passing one of the arrows through the loop and walk to the other end (C) of the 30-yard line in the direction of B. Let some one standing

exactly over D dress the observer exactly with B (by calling out quarter or half pace, &c., right or left, until the right side of head of observer covers the mark B).

5. The observer, facing the same way as in previous operation, now looks at B revolving the end of cylinder until the object A is reflected on B.

Directly this is done the line opposite the fixed zero will represent the distance of the object A in yards.

Should it so happen (and the occurrence would be very rare) that no natural or other prominent object is to be found somewhere near at right angles to A to use as a mark, then a man can run out with a lance, rifle, &c., and place himself at any position near the right angle at any distance over 60 yards.

The observation may be made the reverse of above if no suitable object is found to the left (see Fig. 120). The only thing is to turn

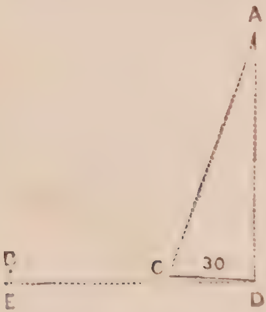


Fig. 119.

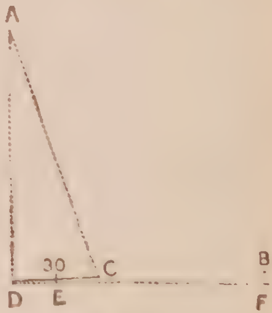


Fig. 120.

the instrument over and follow the same instructions as above, reading "right" for "left."

The base may be paced, instead of measured, when approximate accuracy is sufficient, and time is of consequence.

The length of base may be half (viz. 15 yards) or double (60 yards), and the results will be half and double respectively of the distances shown on the drum of instrument.

Observations may be checked by stopping at 15 when using the 30 base, and taking an observation there.

If no second person is at hand to dress the observer with the mark B, and greater accuracy is required than can be obtained by walking straight by the eyesight in the direction of B, the following plan may be resorted to:—

For Laying out the Base.—Note the object you intend taking as a mark about at right angles to the object, then walk about

33 paces in the direction of it, see that nothing obscures the object or mark, and place a sword or picket through loop of line; now return, unwinding the 30 yards of line as you go, and when at the end move right or left until the picket is aligned on mark. Then proceed as in previous directions, paragraphs 1, 2, 3, at this point (D), and on going to C turn cylinder until object and mark coincide. Read off the distance in yards opposite zero.

When time is of consequence very good results can be obtained by walking the equivalent number of paces to 30 yards in the direction of mark, placing the picket or sword, and pacing the same number back, taking mean of error in doing so, and aligning picket as before.

Another plan for use by one person only:—

(This illustration, Fig. 120, is shown the reverse way to that generally adopted; that is, looking right instead of left.)

1. Use a line 15 yards long, and place an arrow or picket through the loop of it at E. Set the instrument to zero as before, and looking through it in direction of B see which object will coincide nearest with the reflection of A.

2. Walk to end of the line at D, and, moving right or left, stop when E is aligned with B, and place a mark or picket in that position, then look through the instrument and turn small-toothed wheel until A is exactly reflected on mark B.

3. Now take the line, and walking past E stop at extremity of it (C), when E and D are aligned, right about turn very exactly so as not to shift the position.

4. Face B, and on looking through the telemeter rotate the end of cylinder until A is reflected on B. The range can now be read off opposite the zero.

In rotating the cylinder it is better to stop exactly at the point where the object aligns the mark; and if it goes beyond, then it should be turned back and gradually brought up to the mark again. This precaution, although not absolutely necessary, ensures greater accuracy.

If time permits, a second observation can be taken, and the mean of the two readings taken as the distance of object A.

The Use of the Labbez Telemeter as a Surveying Instrument.— The instrument will determine the distance apart of two inaccessible objects by laying out a triangle as follows.

Let A and B (Fig. 121) be two points inaccessible from point C. Having measured with the telemeter the distance C A and C B, carry on in these two directions proportional lengths C B′ and C A′.

The triangle A′ B′ C being similar to the triangle A B C, one has

$$A B = A' B' \times \frac{C B}{C B'}.$$

at the other end is an adjusting screw D, carrying the other support Y′, and fitted with a socket.

The "Y" Level.—This instrument, illustrated by Figs. 123 and

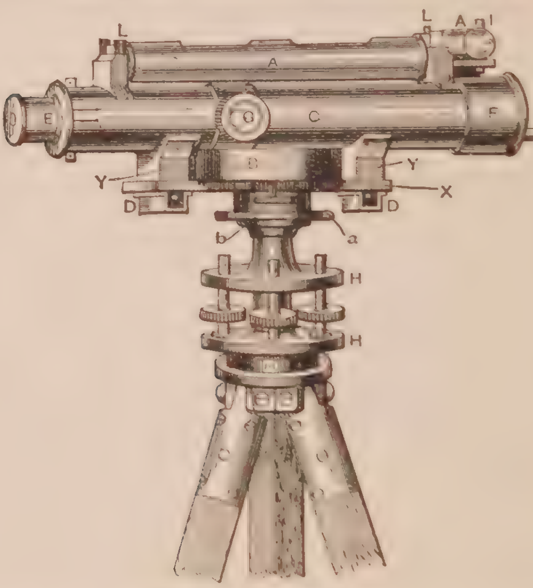


Fig. 124 (Dumpy Level).

125, has its supports Y and Y made exactly similar to those of the Y theodolite described on page 47, so that the telescope C may be

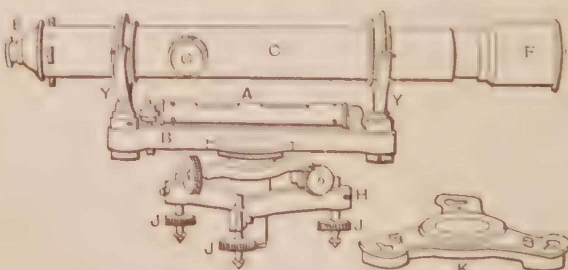


Fig. 125 (Y Level).

removed if necessary by raising the clips. In some cases, as in Fig. 123, there is attached to the telescope underneath a spirit-level, fixed at one end by a joint and at the other by a capstan-headed

screw, for the purpose of adjustment. This method of carrying the level is only adopted in cases where the compass-box B′ is inserted in the stage. Fig. 125 shows how in the absence of the compass the level A is attached to the stage B. Some Y levels are

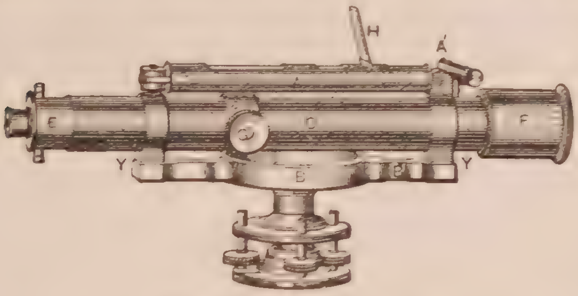


Fig. 126 (Dumpy Level).

provided with a clamp and slow motion arrangement, similar to that described in the theodolite, for the purpose of taking magnetic bearings.

The Dumpy Level.—This is the most approved instrument, the

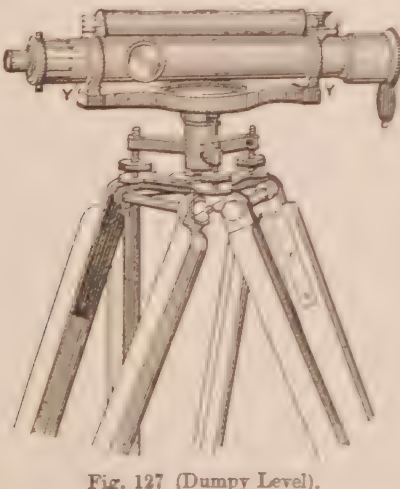


Fig. 127 (Dumpy Level).

telescope being permanently fixed to the stage in the supports, the method of so fixing it varying with the peculiarity of make, as are illustrated by Figs. 124, 126, and 127. In Fig. 124 it will be noticed that the telescope C simply rests in the jaws of the sup-

A′ B′ is known as it can be measured directly, and the product $\frac{C\ B}{C\ B'}$ is an equality of it.

The following is a simple method of carrying out the above instructions.

Find by the telemeter, by method previously described, the distances of A and B from C. Place a man or picket at one-tenth of the distance of C B, *i.e.* at B′, in a line with B. Set the telemeter to its zeros and walk in the direction of A from C, keeping in

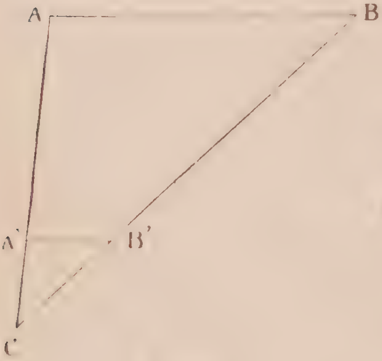


Fig 121.

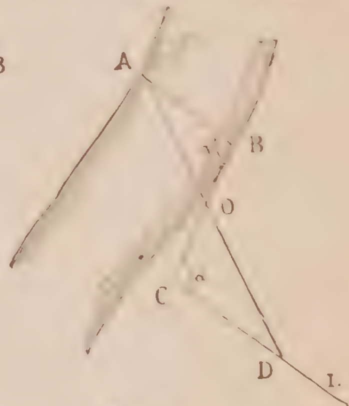


Fig. 122.

dressing with A until B is reflected on A. The distance between A and B will be ten times that of A′ and B′.

Any other proportion can be taken, but if the point at one-tenth is accessible that is the most convenient, being decimal.

To Measure the Width of a River.—Make an imaginary line, C L, by pickets, parallel to breadth of the river at A B, Fig. 122, by forming two equal angles at B and C, then draw a line through O at the half of line C B till it touches line C L (at D), the distance from D to C is the same as the breadth of the river.

The telemeter also enables the observer to—

1. Raise a perpendicular from a point.
2. To draw a line from a point perpendicular to a straight line.
3. To draw a straight line parallel to a given straight line.
4. To prolong a straight line beyond an obstacle.
5. To measure a surface of land.
6. In making of plans.
7. In making military reconnaissance of a zone of land or of a road in time of peace or war.

The price of the telemeter in pocket bag is from £2 15s. to £3 3s.

The Level.—There are various types of levels, the peculiarities of which are identified with their maker, but the chief with which the surveyor has to do are the "Y" and the "dumpy," the former being illustrated in Fig. 123, and the latter in Fig. 126. In almost every case these instruments are supported upon tripod-stands, similar to those described for the theodolite, varying in their size and strength with the nature of the level. Some makers have substituted for the parallel plates and four screws the tribach or three-screw arrangement (Fig. 125), whereby a three-arm-plate forming a part of the body-piece is substituted for the upper parallel plate; and indeed there are levels with parallel plates but having only three screws. Such arrangements may give greater

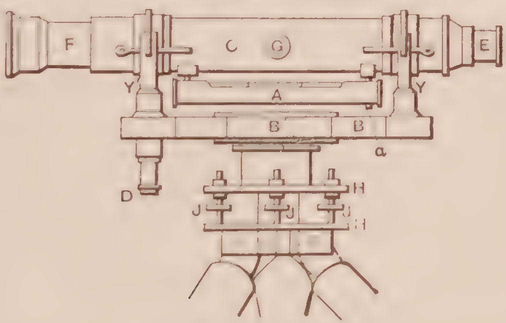


Fig. 123 (Y Level).

delicacy in levelling, but for good practical use there is nothing to equal the parallel plates and four screw system.

The vertical axis of the level made conical in shape and solid forms part of the upper parallel plate, upon which turns easily the body-piece supporting the instrument, which is connected with the vertical axis by means of a washer and fixed screw. This body-piece is turned most accurately to the same shape as the vertical axis, which is connected with a half ball and socket fitted into the domed socket of the lower plate and securely screwed. The upper and lower parallel plates are kept apart by the four milled-headed screws, one of which is held in position by a stop-block attached to the lower plate.

Thus it may be taken that up to this point all levels are similar in construction, but beyond this the difference between the "Y" and the "dumpy" should now be described.

Screwed upon the outer jacket or body-piece forming the vertical axis is the stage or horizontal bar B (Fig. 123), so formed that a compass-box B′ may be inserted, as shown in Fig. 126. At one end of the stage is a joint carrying one of the supports Y, whilst

ports Y Y, whilst in some dumpy levels the telescope is contained within two collars, to one end of which, by a hinged joint, the spirit-level is attached, whilst upon the other is fixed a capstan-screw, for the purpose of adjusting the axis of the telescope horizontal to the spirit-level when in the centre of its run. This is an unquestionable advantage, for the makers of the better class of instruments adjust this axis to that of the level so accurately that except under extraordinary circumstances, such as substituting a new bubble-tube, it should very seldom or ever require attention. Troughton's improved level (Fig. 128) is arranged so that one support is connected with the stage by a hinged joint, whilst the other has an adjusting screw working through a spring fixed

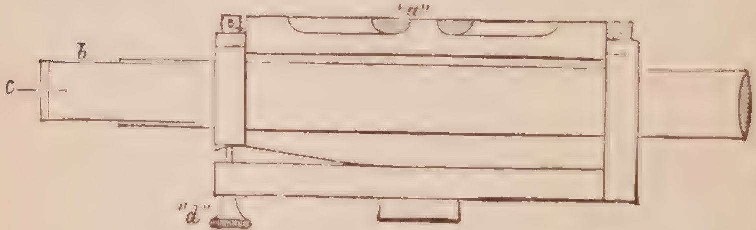


Fig. 128.

on the stage and through the stage itself, and actuated by a capstan head, which, when not required to be used, is protected by a screw-cap.

Telescope.—The telescope, which is held within the supports, consists of two tubes, the outer containing the object-glass F and its shield, and the inner tube, not quite so long, carrying the diaphragm and eye-piece.

Object Glass.—The object-glass consists of what is known as a compound lens, composed of a plano-concave and double convex glass, forming together plano convex lenses; and the plane sides are presented towards the object.

Eye-piece.—The eye-piece, invented by Ramsden, consists of two lenses of equal focal lengths, one plano-convex and the other convexo plano, so that the convex sides are turned towards one another, the interval between them being two-thirds of the focal length of either.

The Diaphragm.—The diaphragm (Fig. 129) consists of a brass ring A of smaller dimensions than the inner tube, to which it is fitted by four capstan-headed screws c c^1 c^2 c^3 for the purpose of adjusting the ring. Attached to this ring are what are termed the cross-wires, consisting of two vertical, a and b, and one horizontal

pair, *d*, and which usually are the web of a common garden spider wound round a forked piece of stick (Fig. 130), with which the lines may be accurately attached to the ring with a little gum or wax.

"In looking through a telescope a considerable field of view is embraced: but the measurements, indicated by any instrument, of which the telescope may form a part, will only have reference to one

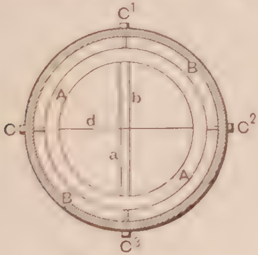


Fig. 129.

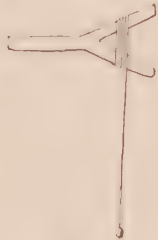


Fig. 130.

particular point, which particular point is considered as the centre of this field of view. We must therefore place some fixed point in the field of view, at the focus of the eye-piece, and the point to which the measurement will have reference will be that point of the object viewed, which appears to be coincident with this fixed point, or which, as the technical phrase is, is bisected by the fixed point." The intersection of the two vertical and the horizontal wires of the diaphragm furnishes us with this fixed point.

"When the instrument is in adjustment [*i.e.* the diaphragm has been truly adjusted so that the cross-wires are coincident with the centre of the field of view], the axis of the tube of the telescope is set truly horizontal by means of the level beneath it, and the line of observation ought consequently to be parallel to this axis. Let A (Fig. 131) represent the proper position of the intersection of the cross-wires, and O A the direction of the axis of a pencil of light passing through the object-glass and coming to its focus at A. Then, the axis of the tube of the telescope being set truly horizontal, the line A O is also truly horizontal, and every point bisected by the intersection of the cross-wires will be situated on the prolongation of the horizontal line A O.

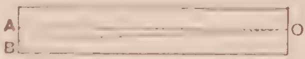


Fig. 131.

"Suppose now the position of the diaphragm carrying the cross-wires to have become deranged, so that the point of intersection is moved to B, then every point bisected by the intersection of the cross-wires will be on the prolongation of the line B O, and will, consequently, be below the true level point on the line A O."*

* "Surveying and Astronomical Instruments," p. 13, by J. F. Heather, M.A. Crosby Lockwood & Son, London.

Line of Collimation.—"The error from misplacement of the spider-lines has a technical denomination. The line O A, or O B, from O to the point of intersection of the cross-wires, is called the *line of collimation*, and the error arising from their derangement . . . . is called the *error of collimation*." *

Adjustment of the Level.—The following is a copy of the instructions issued by Messrs. Troughton and Simms with all their levels.

"Art. 1.—When the bubble '*a*' (Fig. 128) is in the centre of its run the direction of the movement of the draw *b* should be horizontal.

"Consequently there can be but one position for this level, which, having been determined by the maker of the instrument, may be regarded as constant.

"The insertion of a new level will alone disturb the relation which exists between the level and the telescope; in such a case a re-determination of its position will be necessary.

Fig. 132.

"The screws *e e* (Fig. 132) are supplied for the purpose of bringing the bubble into the position indicated in Art. 1. Unless the level be broken they should not be touched, and after the new level has been inserted, if once adjusted, no correction will subsequently be needed.

Adjustment for Collimation.—"Art. 2. The line joining the optical centre of the object-glass and a point in the line of the horizontal wire should be horizontal when the bubble *a* (Fig. 128) is in the centre of its opening.†

"This adjustment is effected by the collimation screws at the eye end of the instrument which serve to raise or depress the wire-frame or diaphragm. Whenever the object glass has been removed, a re-determination of this adjustment, known as the adjustment of the line of collimation, will be necessary.

"Art. 3. The horizontality of the line of collimation should be maintained during a complete revolution of the instrument upon its axis. In order to effect this adjustment the bubble *a* is brought into the centre by means of the parallel plate screws. The telescope is then turned 180 deg. upon its axis; should the position of the bubble have changed, half the difference between this new place and its old position has to be effected by the parallel plate screws and the remaining half by the screw *d*, which is placed inside a cap under the stage. This adjustment is known as the adjustment for reversion; it is comparatively of little importance, and can, in our instrument, be accomplished at any time in a few seconds.

To Adjust for Collimation (Fig. 133). "Place the instrument

* "Surveying and Astronomical Instruments," p. 15.

† This is technically known as "being in the centre of its run."

exactly half-way between the two staves held at any convenient distance from each other, bring the bubble *a* to the centre of its run and read both staves; the points thus obtained will be equi-distant from the earth's centre, and consequently level. The instrument may now be set up nearly in line with the staves, but not between them; the bubble *a* must be brought to the middle of the opening, and, by means of the collimating screws, the horizontal wire *c* may be made to bisect the two level points or others equidistant therefrom.

"If the distance between the more distant staff and the level be considerable, allowance is to be made for the curvature of the earth. An adjusted level (used as a collimator) will supply a ready means for the accurate adjustment of other instruments. In order to effect this purpose, the wires must be placed in the principal focus of the object-glass, the eye-piece should be removed from its socket, and, as a temporary protection for the webs, a piece of plain glass may be inserted. The level should now be erected, and the bubble brought accurately into the centre.

"Let A be the adjusted level; B the instrument, the adjustment of which is to be checked; a pencil of rays proceeding from a point in the plane of the horizontal wire *c* will, after passing through the object glass, be parallel, and, should the axis of the pencil be horizontal, the parallel rays will after emergence be also horizontal. It will be perfectly clear that if the level A be in adjustment, and the bubble *a* in the centre of its opening, the horizontality of this parallel pencil is ensured.

"The level under adjustment, B, is to be placed with its object-glass in front of the object-glass of A. As the diagram indicates, a little difference in the height of the instruments will not affect the result; but it is desirable that there should be no great difference. The parallel rays from A falling upon the object-glass of B will be converged to a point within the telescope, and an image *c′* of the wires *c* will be formed.

Fig. 133.

"If the bubble a' of the level B be brought into the centre by the parallel plate screws, and the level B be in adjustment, the wires in B will lie upon the image of the wires in A. Should this not be the case, let them occupy a position as c''; the operator will now have to release the lower collimation screw and to tighten the upper, thereby raising the wire frame (diaphragm) until he has brought c'' upon c'; when this has been done (provided the bubbles in both instruments retain their central position) the adjustment for collimation has been accomplished."

Adjustment for Parallax.—There is another adjustment of the level of great importance, and that is what is termed parallax, or when the image of the object viewed formed by the object-glass falls either short of or beyond the place of the cross-wire. The existence of parallax is determined by moving the eye about when looking through the telescope and observing whether the cross-wires change their position and are flittering and undefined.

To correct this error first adjust the eye-piece by means of the movable eye-piece tube, till you can perceive the cross-wire clearly defined and sharply marked. Then by moving the milled-headed screw G, which by a rack and small pinion wheel within the telescope enables the internal tube to be thrust out or drawn in to focus the object, according to distance, and you are able to see, at the same time, the object clearly and the intersection of the wires clearly and sharply defined before it. The existence of parallax is very inconvenient, and when disregarded has frequently been productive of serious error. It will not always be found sufficient to set the eye-piece first and the object-glass afterwards. The setting of the object-glass by introducing more distant rays of light will affect the focus of the eye-piece and produce parallax or indistinctness of the wires where there was none before. The eye-piece must in this case be adjusted again.

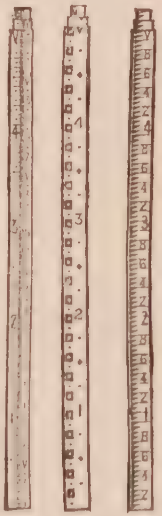
Generally, when once set for the day, there is no occasion for altering the eye-piece, but the object-glass will of course have to be altered at every change of distance of the object. The nearer the object is to the instrument the greater length will the inner tube have to be drawn out; but there is a limit even to this, as the figures on the staff are indiscernible within a few yards, and the greater the distance there is between the instrument and the object, so much shorter must the telescope be. The best 14-in. levels will only read figures clearly at a distance of about 150 yards.

It should be noted that the correction for parallax should be made previous to that of collimation.

Reflecting Mirror.—There are several appendages to the level, such as a reflecting mirror, which by means of a saddle-shaped clip may be fixed upon the bubble-tube, and having a hinged

joint may be placed at such an angle as to enable the operator to see if the bubble is in the centre of its run at the same time he is looking through the telescope. There is also provided a magnifying glass, which fitting into a socket attached to the side of the compass-box, is used to facilitate reading the magnetic bearings. The needle, when not required, may be thrown off the agate centre by means of either a screw or a lever fixed in the side of the compass-box. The cost of a good level varies from £12 for a 10-in. to £16 10s. for a 16-in. instrument.

Levelling Staff.—There are various types of levelling staves: the chief with which the surveyor has to do, however, being what is called the telescope staff. This consists of a mahogany box 5 ft. long, 4 in. broad, and $2\frac{1}{2}$ in. deep, within which is another hollow box 4 ft. 6in. long, made so that it will slide easily within the other, whilst another solid mahogany staff again works within the inner one, so that when pulled out to their full length, having springs or clips to secure them, it represents a staff 14 ft. long, which when not required can, by sliding the divisions one within the other, be made compact for transit, as represented by Figs. 134, 135, and 136, which illustrate the usual method of graduation.



Figs. 134, 135, 136.

The face of this staff is either covered with printed papers or, preferably, is painted so as to represent each foot from 1 ft. to 14 ft., which are again subdivided into hundredths of feet, the feet being represented by red figures and the subdivisions by black.

It must be understood that the tops of the red figures represent the value in the feet upon the staff; but in the subdivisions, whilst the tops of the black figures, which are always odd numbers, represent their value in hundredths of feet, the bottoms of these same figures represent the intermediate even numbers. Thus by reference to Figs. 134 and 137 it will be seen that there are in each foot five figures respectively, 1, 3, 5, 7, and 9, representing $\frac{10}{100}$, $\frac{30}{100}$, $\frac{50}{100}$, $\frac{70}{100}$, and $\frac{90}{100}$. Consequently the bottoms of 3, 5, 7, and 9 of the black figures and the top of each red figure represent $\frac{20}{100}$, $\frac{40}{100}$, $\frac{60}{100}$, $\frac{80}{100}$, and $\frac{100}{100}$. Fig. 138 shows a tenth of a foot and $\frac{6}{10}$ths of another, and each $\frac{10}{100}$ is delineated by a black stroke across the left side, the bottom white stroke representing $\frac{1}{100}$, the next black stroke $\frac{2}{100}$, the next white stroke $\frac{3}{100}$, the next black $\frac{4}{100}$, the next white $\frac{5}{100}$; at five is a longer stroke, and consecutively each white and black stroke make up the sum of $\frac{10}{100}$ to the top

of the 1 of the black subdivisions. By a similar process is made up the $\frac{1}{100}$ of the next subdivision to the bottom of the 3, and so on seriatim.

In using the staff the observer must notice carefully where the horizontal wire of the diaphragm cuts the staff, counting the red figures from the bottom and the nearest subdivision—in other words, supposing the wire were to cut the staff between the red

Fig 137.

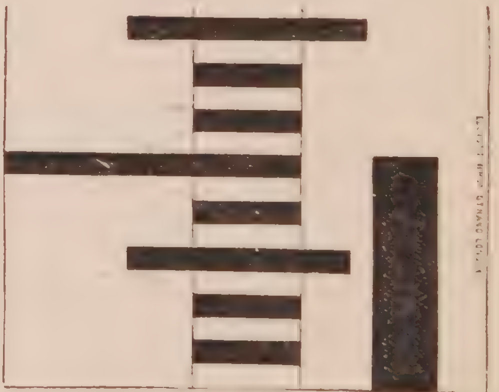


Fig 138.

figures 5 and 6 and above the black figure 3 of the subdivision and intersect the second of the black strokes, it would represent that the line of collimation cut the staff at 5·31 ft.

The greatest care should be observed in holding the staff so that it be perfectly vertical, for which purpose a plumb-bob is sometimes used, and cases have been known where a small spirit-level has been inserted at the back of the lower member of the staff to guide the staff holder in keeping it perpendicular; but judgment is all that is necessary on the part of the staff holder if he can be induced to gently move the staff backwards and forwards towards the observer, the true reading being the smallest. My reason for saying this is that during a very large experience with men of almost every nationality, and under varying circumstances, I have had no

difficulty in educating them to carry out my wishes in this respect, the result being satisfactory.

The preceding description is that of a 14-ft. or the usual kind of levelling staff, but they can be obtained 16 or 17 ft. long and made proportionately, the figuring of course being the same kind. There is no doubt a considerable advantage in the use of such staves, especially in hilly country, but in winter weather it is often difficult for a man to maintain a vertical position with so long a staff.

The cost of a 14-feet levelling staff is from £2 10s. to £3 3s.

The Aneroid Barometer.—This invaluable instrument, the invention of which is attributed to M. Vidi of Paris, is greatly used by surveyors for ascertaining great altitudes, where the ordinary

Fig. 139.

operation of levelling is impossible, or for approximation. The action of this barometer, "for ascertaining the variations of the atmosphere, depends on the effect produced by the pressure of the atmosphere on a metallic box, hermetically sealed, from which the air has been previously exhausted." * This box (*a* in Fig. 139 and A in Fig. 140) is corrugated upon its upper and lower surfaces, and by means of an elaborate system of levers and springs the index, or hand, is made to traverse the dial which surmounts the frame, being actuated by increase or diminution of the atmospheric pressure upon the metallic box. The aneroid thus "records the changes in the weight or *pressure* of the atmosphere on a *given surface*, suppose a square inch; and it would, therefore, have greatly

* "Surveying and Astronomical Instruments," p. 104, by J. F. Heather, M.A. Crosby Lockwood and Son, London.

facilitated the comprehension of the action of the instrument had the dial been graduated to show the difference of the atmospheric pressure in absolute weight or pounds;" but seeing that "the density of the atmosphere would decrease in geometrical progression, for altitudes in arithmetical progression, and since this density also varies directly as the pressure to which it is subjected, and which is measured by the height of the barometric column, it follows that, if at different altitudes these columns decrease in geometric progression, the altitudes will increase in arithmetical progression, and will therefore be proportional to the logarithms of the barometric columns. Hence, if the temperature remained constant, the difference of two altitudes would vary as the difference of the

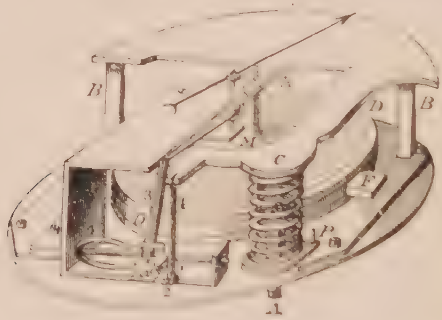


Fig. 140.

logarithms of the barometric columns at those altitudes; so that if h be taken to represent the height of a higher station above a lower one, and if B be the height of the barometer at the *lower* station, and b the height at the *higher* station, we should have

$$h = k \log. \frac{B}{b};$$

where k is a constant quantity, to be determined by experiment." I cannot do better than refer the student to the very exhaustive consideration of the theory of the aneroid in the work by Mr. Heather, from which the foregoing is extracted.

It should be stated that the variation of temperature greatly affects the results of observation with the aneroid. To guard against any error a thermometer is attached so that the difference of temperature may be noted at the various stations.

Fig. 139 is a plan of the aneroid with the dial removed, and Fig. 140 is an isometrical view of the same. The instrument is from 4 to 5 in. in diameter (some even larger) and about 1¾ in. thick. "The pressure of the atmosphere is indicated by the hand h (Fig. 139) pointing to a scale, which is graduated to correspond with

the common barometer." There is also a scale compensated to agree with the altitudes in feet, which is attached by a movable rim so that its zero may be regulated as necessary. Referring to Fig. 140, A is the screw adjusting the hand, B B the fulcrum, C C the principal lever, D D the vacuum vase, 1 vertical rod connecting lever C C with levers 2 and 3, *e b* adjusting screws for leverage, S spiral spring, M socket in vacuum vase, K pin attached to socket.

The cost of an aneroid barometer varies from £3 3s. to £8 8s.

The Stadiometer.—This is one of those instruments for expeditiously measuring distances (illustrated in Fig. 141). It consists

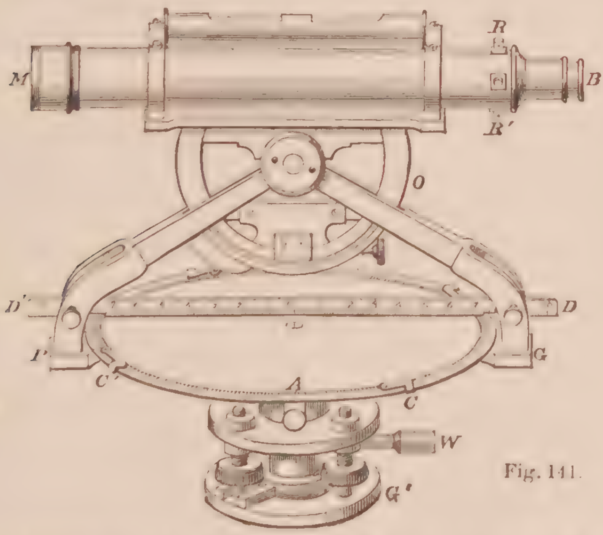


Fig. 141.

of a telescope M B, fitted to a vertical arc O, which works in the frame P G which is attached to the body-piece of the instrument, and above which a round disc or table A rotates. "There is a scale D D′ fastened to the frame, the centre of which corresponds with the centre of the instrument, and which is graduated to the scale to which the surveyor wishes to plot his work. The telescope M B is fitted with a diaphragm, with two horizontal hairs, distant from one another a hundredth part of a foot of the focal length of the object glass. From this proportion it follows that, when any ordinary levelling-staff is held on any distant point and the telescope brought to bear upon it, if the readings, in feet and decimals of a foot, of the intersections of the hairs on the staff be observed, their difference multiplied by a hundred gives the true distance in feet of the staff from the instrument."

The Omnimeter.—"This instrument (Fig. 142), like the stadiometer, is intended to measure base lines and distances without chaining, and also the differences of altitudes and angles." It consists of a graduated limb (1) reading by means of a vernier to ten seconds for the measurement of horizontal angles; a good telescope (2) revolving in a plane perpendicular to the limb; a powerful microscope (3) closely united to the telescope; a highly sensitive level (4) lying upon the rule (5) which has a fixed length (of twenty centimetres, for example); a scale (6) fixed vertically at the extremity of the said rule, in the plane of the optical axis of the microscope, and divided into half-millimetres, the millimetres only being indicated by figures from 1 to 100; a micrometrical screw (7)

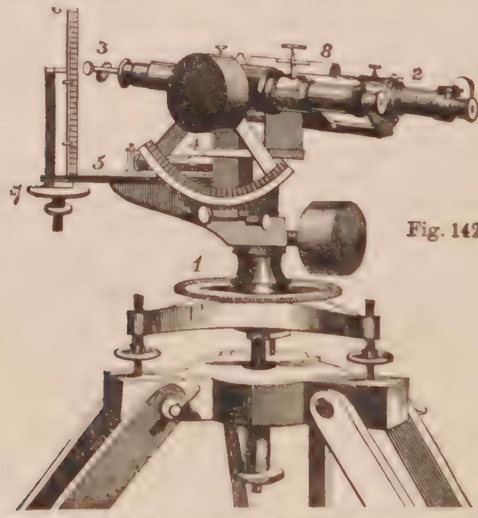


Fig. 142.

attached to the base of the scale, and giving a correct reading of the scale to the $\frac{1}{10000}$ of a millimetre, denoted on the graduated circle of the screw; an extremely sensitive level (8) capable of being applied to the telescope, and for determining in case of necessity its horizontality.

Accompanying the instrument is a staff of a fixed length—say three metres—having a white mark upon a black ground at either end. This staff is held at the point of which the distance from the instrument is required, and the telescope having been directed to the staff, which must be held perfectly plumb, the inclination is read off by means of the microscope from the scale. This being done, the distance may be calculated.

The Tacheometer.—Whilst for military or approximate purposes appliances such as the foregoing may be very useful and expeditious, I do not hesitate to confess a predilection for ascertaining the lengths of my base and other lines by actual measurement. There is, however, another instrument—the tacheometer—for determining distances otherwise than by measurement, which during recent years has come into more frequent use by English engineers, but it can only be mentioned here.*

Dredge-Steward Omni-telemeter.—This excellent instrument, originally intended to be only a range-finder, has, upon the advice of Colonel Fraser, R.E., been improved to an extent which proves it to be "a very accurate instrument for telemetric surveying."

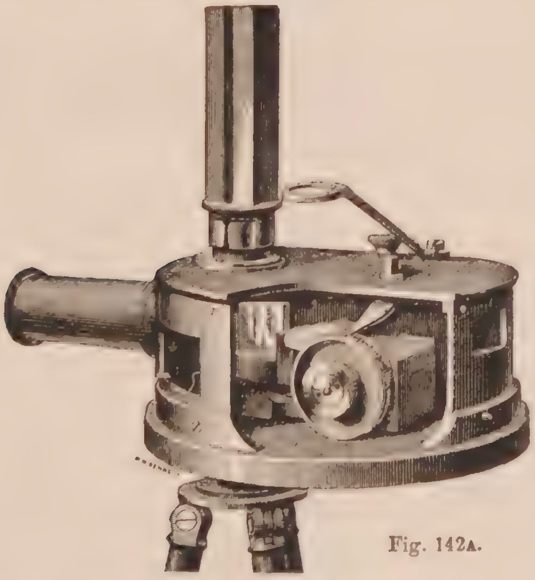


Fig. 142A.

The general view of the instrument is shown in Figs. 142A and 142B, whilst Fig. 142C shows a section through it. From these

* In 1890, a paper on "The Tacheometer" was read before the Institution of Civil Engineers by Mr. Neil Kennedy, M.Inst.C.E.; and a work by the same author—entitled "Surveying with the Tacheometer"—was issued in 1900 by the publishers of the present work (see page 12 of Catalogue at end of this volume).

"Tacheometry" was also the subject of papers read before the same Institution by Mr. Bennett H. Brough, in 1887, and by Mr. R. E. Middleton, M.Inst.C.E., in 1894.

it will be seen that the instrument is a modification of the ordinary box sextant, but in place of the two mirrors of the instrument being parallel to each other, when the graduation reads 0, the mirrors of the omni-telemeter make an angle of 45° with each other in this position, so that on looking through the instrument under these conditions the eye of the observer occupies the apex of a right angle, the sides of which are formed by

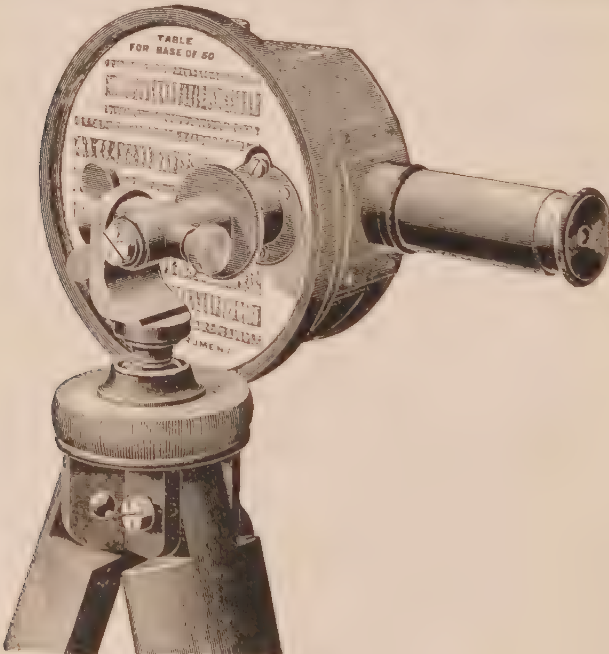


Fig. 142B.

the direct line of sight, and that seen by reflection in the two mirrors.

There is still another point in which the instrument differs from the box sextant. In that instrument, as is well known, one of the mirrors, viz., that known as the horizon glass, is fixed in position, whilst the fully-silvered mirror only can be adjusted. In the Dredge-Steward instrument, however, both these mirrors are adjustable. Referring to Fig. 142C, D is the mirror which is fixed in the sextant, but which, in the present instance, can be adjusted through a limited range by means of the micrometer screw E. This mirror is mounted on an arm B, which, turning

round the pivot F at one end, is kept in contact with the screw E already mentioned by the spring O, and it is by moving this arm that the mirror O is adjusted. At the free end of this arm is a nut C, carrying a micrometer screw with a graduated head G, as shown. The other end of this screw abuts against the arm

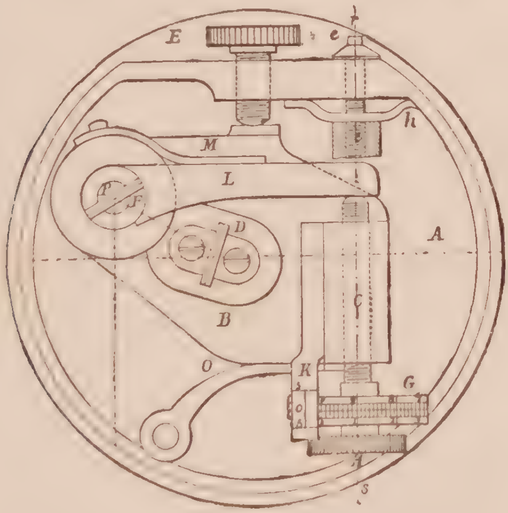


Fig. 142c.

L, on which the fully-silvered mirror P is mounted, and which can, therefore, be rotated through a small angle by turning the milled head H of the micrometer screw.

In using the instrument to take a range, as A B (142F), the observer being at B, and facing so that the mark lies on its right hand, he views it by reflection in the instrument. The line of sight from the object reaching first the mirror P, is reflected on to the mirror D (Fig. 142c), and from it to his eye. The observer now, looking through the unsilvered part of the mirror, tries to find some prominent object C (Fig. 142D), which he can superimpose on the reflected image of A, without, be it understood, touching the micrometer screw H. When this is done the angle A B C is a right angle. Now putting a mark at B, he paces in the direction of C B produced a distance B D = 50 yards, and looking again

Fig. 142D

through the instrument as before, he turns the milled head H until the image of the mark A is again superimposed on C. Then reading the index on the micrometer screw, and referring to a short table attached to the instrument, he reads off instantly the range A B.

Usually it is impossible to get a mark C, such that the angle A B C is a right angle, without several trials, and it is here where the advantage of the omni-telemeter comes in, since it is not necessary with this instrument that the angle A B C shall be a right angle. Hence, if a point cannot be found fulfilling this condition, the observer chooses some point that nearly does so. Looking at this object and the mark through the instrument, when the latter is adjusted in its zero position, the image of the mark will be to one side or the other of it. In this case the

Fig. 142E.

screw E is turned round, moving the mirror until coincidence is secured, and the second observation is taken at D (Fig. 142D), as before. Owing to this adjusting screw E, much less trouble is required to find a suitable mark on which to project the object whose range is sought.

In the case of instruments having a fixed base angle, the observer may have to shift his position considerably before the desired coincidence is obtained. The adjustment allows base angles varying 8 deg. on either side of 90 deg. to be used, and it, therefore, is only in very exceptionally monotonous countries that a suitable mark cannot be obtained with comparative ease.

The best plan of using this instrument is indicated by Fig. 142E. A stick is placed at the point A, and distances of 25 yards measured on each side of it. Then to get any range such as E, a suitable object such as L is taken, and the observations taken

at the points B and C. To take the distance of the point G a man is sent out with a picket to O, and used as the auxiliary mark. For the range of the steeple F the mark M would be used, and J when taking H. In this way a whole round of objects can have their distances ascertained very rapidly. With moving objects two instruments are used, held by observers 50 yards apart, the line between them making an angle of nearly 90 deg. with the object. Both of the instruments having been first set to zero, each observer reflects the other on the object by using the micro meter screw H (Fig. 142C). The range is then got by adding or subtracting the readings of the two instruments, the sum being taken when the zero line of the two is on the same side of the zero line of the scale K, and the difference when they are in opposite sides. An optical square and one instrument can be used.

For telemetric surveying the following method of using the instrument has been worked out by Colonel Fraser, and is illustrated in Fig. 142F. The instrument is mounted on its stand in the position shown in Fig. 142B, and a bright object — Colonel Fraser uses a gilt prism — is placed on the ground vertically below it by means of a plumb bob. The instrument is then set to zero. An assistant is sent out to the object, whose distance is required, with a staff having targets 5 ft. apart, the lower one being 2 ft. 6 in. from the ground. This target is aligned with the image of the ground mark by means of the compensating screw E, and afterwards the upper target is aligned by means of the index screw, the reading of which then gives, by reference to a table, the distance of the staff. This method can be employed in all cases when the slope does not exceed 8 deg., that being the limit of adjustment by the compensating screw. At the same time the instrument can also be used to ascertain the heights of objects, the distance of which is known. For this purpose the instrument is mounted on its stand as already described, and the base of the object being reflected by the compensating screw on to the plumb bob, and then its summit by the other screw. The height of the object is then obtained from a table of rise in inches per yard.

Fig. 142F.

It is obvious that the instrument can also be conveniently used as an optical square, and hence (having regard to what has been

already stated) it would appear that it can be used almost as a universal instrument for preliminary survey work.

The Francis Surveying Compass and Clinometer.—This is a new surveying instrument, invented by Mr. W. R. Francis, of Swansea, and designed especially for work in mines. It is capable, however, of performing all kinds of work that do not require an exceptional degree of accuracy. The main part of the instrument (Fig. 142G), apart from the stand, will go into the side pocket of a coat, when the compass is set in plane of the frame, and may be thus carried with safety. The total weight of the instrument, with case, fittings, stand, and plane table, is about 17 lbs. only. The whole apparatus, being a light one, could be easily transported by one person across a difficult ground, and is thus very suitable for explorers in new countries.

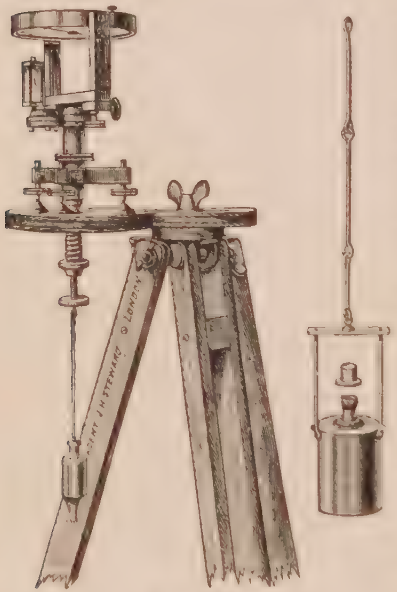


Fig. 142G.

The graduated circle of the compass is 3½ in. in diameter, and can be adjusted to correct the deviation of the needle. This latter is blunt-ended; it is silvered near its tip, and a fine line is drawn along its centre to read the deflections by. This adds considerably to the facility of using it, and angles can be read within a ¼ deg. As is usual, there is a device by which the needle can be lifted off the central pin to reduce wear in travelling, and also to aid in bringing it to rest. Sights are taken by means of two vertical slots in the frame; these are formed with bevel-edged plates,

Fig. 142H.

and give a very clear and exact vision of the object under view. The frame itself can be rotated on a vertical pivot on the three-armed stand, while fine adjustments are made by a screw with a milled head. A second screw serves to clamp

the frame in position. The compass is levelled by a single bubble, the levelling screws having ball-and-socket heads, enabling them to take a firm bearing in all positions, when the instrument is fixed by a central screw (Fig. 142H). This is a new feature, at least in this country.

The measurement of vertical angles is effected by unshipping the rectangular frame, and mounting it horizontally by means of the right-angled fitting shown at Fig. 142I in the lower view.

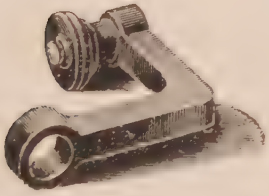


Fig. 142I.

Fig. 142J.

This brings the compass into a vertical plane, and allows the clinometer needle to hang freely. Any object can then be sighted either above or below the spectator, and its vertical angle read off. The two slots are exactly alike, so that sights can be taken both backwards and forwards without reversing the instrument.

As shown in Fig. 142G, the instrument is set upon an extension bracket fixed to the top of the tripod stand. This bracket is made of three layers of wood glued together with the grain crossing to prevent warping. It has a central hole through which a plumb-line may be dropped when it is desired to work from a certain point. By means of this line the centre of the compass can be set exactly in position. Ordinarily, however, this is not requisite, and then the instrument is fixed directly on the head of the tripod stand by means of the thumb-nut shown. It may also be held in the hand, without any stand at all, or suspended on a slack string passing through the V cuts at the tops of the sighting slits. This latter plan is often very useful in getting round awkward positions in underground surveying, where there is no place for a tripod to stand. The weight of the instrument keeps it steady and plumb, while the V cuts align it directly between the points of suspension of the string.

Fig. 142K shows a straight edge for use with the plane table. It carries a stool on which the compass can be fixed by two

screws, and when this is in position a survey can be laid down directly by the use of the same instrument by which it was made. The plane table, 16 in. by 16 in., can be mounted on the stand and fixed by clamp screw.

The legs of the tripod are telescopic, so as to pack into con-

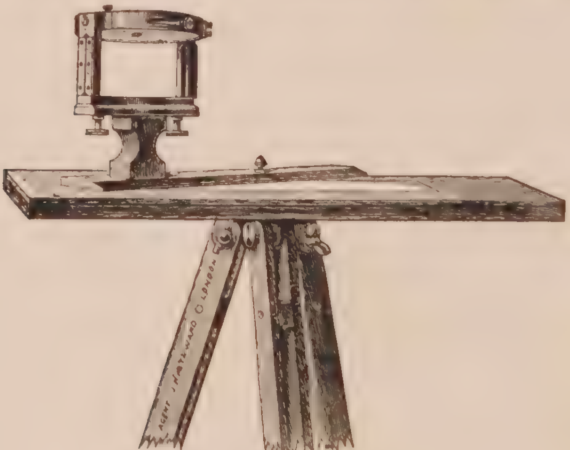


Fig. 142K.

venient length. At the foot each leg carries a step (Fig. 142J), an ingenious device by which the leg can be pressed firmly into the soil.

Stanley's Patent Model Transit Theodolite.—This is unquestionably a great improvement upon the general construction of transit theodolites, for it meets the objection I make on page 56, where, in speaking of the various adjuncts to the instrument, such as lanterns, &c., I say: "My own experience has been that such appendages are more trouble than they are worth, and the extra money would be better spent upon strengthening the working parts of the instrument."

This instrument (Fig. 142L) is constructed (as will be seen by the illustration) upon the solid system as compared with the building up by separate parts, whereby greater rigidity must of necessity be obtained. And the central axis, being one-and-a-half the diameter, is about double as strong as that of an ordinary transit.

"The plate has not to support the superstructure as in an ordinary theodolite, but has only to hold the two axis bubbles, which are thereby brought distinctly in view, and the clamp and

tangent motion, which is also placed conveniently for use upon this plate, in a position where there is less risk of accident than when it is placed upon the outer edge of the limb."

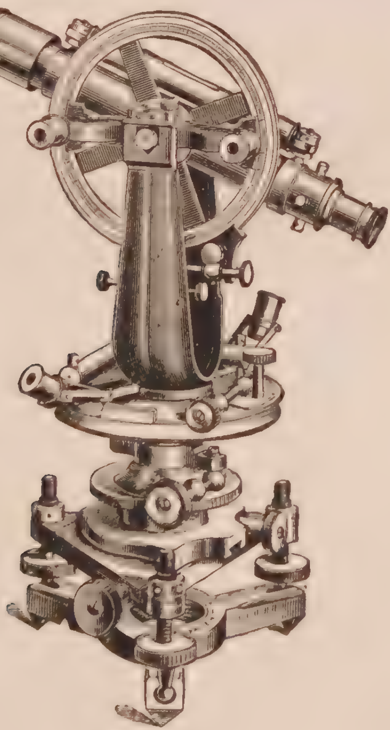


Fig. 142L.

Trotter's Curve-Ranger.—This little instrument, which is shown in perspective in Fig. 142M, is intended to perform all the operations of curve-ranging without, in most cases, requiring any calculation whatever to be made by the operator, as the chord, arc, versin, and many other quantities can be read direct from the scales with which the instrument is provided. The principle is that of Euclid III., prop. 21, where it is proved that the angle in the segment of a circle is constant.

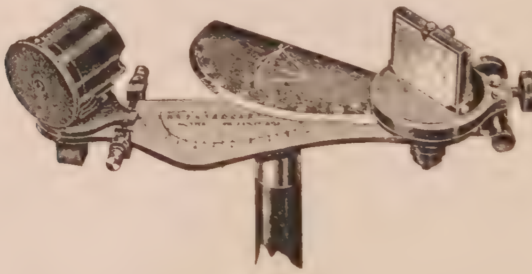
The mirror moves with the upper scale. The figure of the curved edge of this scale is a polar curve whose equation is

$$r = a + b \sin 2\theta$$

where a is the distance from the zero graduation to the axis of

the mirror, and b is the length of the scale from zero to 2, and θ is the inclination of the mirror. On the left of the woodcut is shown an eyepiece containing a half-silvered mirror, set at such an angle that when the instrument is closed, and reads 90° on the graduated limb, it may be used as an optical square.

If three points, A B C, on the curve are given, and all are accessible, set up rods at A and C, place the instrument over B,



142M.

and adjust the mirror by means of the tangent-screw, so that the rod at C is seen direct through the eyepiece, and the rod at A is seen by reflection in the mirror. Then if any intermediate position on the curve be taken up, both A and C can be seen simultaneously through the eyepiece of the instrument, one by reflection, the other by direct vision, superimposed. If the two rods are not seen superimposed, the operator must move to the right or to the left until this is the case. The instrument will then be over a point on the curve. In this way any number of points in the curve can be fixed as the observer moves from A to C, and on arriving at C, the tangent to the curve may be obtained, for when the rod at A is observed by reflection, the direction of the line of sight through the eyepiece is the tangent to the curve, and a ranging rod may be set up at any convenient distance to mark it. Similarly the tangent at the other end of the curve may be found.

On the back of the movable plate, a scale showing the ratio of the length of the arc to the length of the radius, is read at the point where the body of the instrument cuts the graduations. An engraved figure on the instrument shows also all the elements of a curve that can be obtained by direct reading from the scales of the instrument, or by simple arithmetical calculation.

Although the instrument is not intended to replace the theodolite in very accurate surveying, one advantage is claimed for it over the older instrument, in that errors made by it are

not cumulative, and no assistants, chain, or tables are required, as is the case when curves are set out by the method of tangential angles. The only adjustment required is the setting of the eyepiece. This is adjusted as an optical square when the graduated limb reads 90°. Price, with telescope in leather sling case, £10.

Dalrymple-Hay's Curve-Ranger.—This instrument (Fig. 142N),

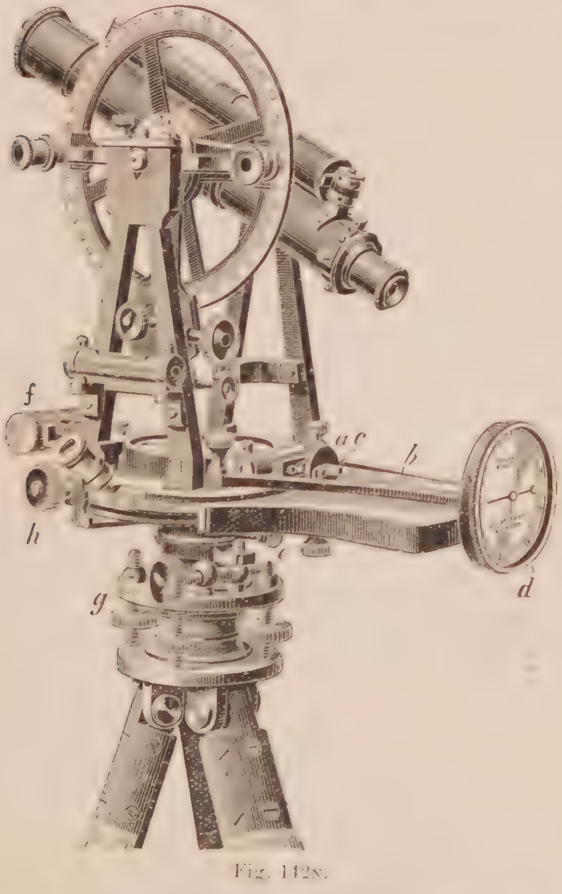


Fig. 142N.

which has been invented by Mr. H. H. Dalrymple-Hay, an assistant engineer on the London and South-Western Railway, is designed to facilitate operations in the field when ranging curves by the method of tangential angles. It can be fitted to

theodolites of any pattern, by simply clamping the horizontal plate to the divided and limb, the arm carrying the dial to the vernier limb by milled screws. This attachment can be readily removed from the theodolite when not required, and will fit into the case of the theodolite.

By simple mechanical movements it at once gives the tangential angle for each chain point in all curves in general use on railways, and thus obviates the necessity of referring to a table of tangential angles, and then reading the vernier as with the theodolite. When ranging new tangents no calculations are required.

Subjoined is a comparison, as stated by the inventor, of the operations involved in setting out a curve by means of the theodolite and the curve ranger respectively:

"Example.—To set out a curve of 60 chains radius.

"*With Theodolite.*	"*With Curve Ranger.*
"1. Set up instrument.	"1. Set up theodolite with Curve Ranger attached.
"2. Set vernier to zero, direct telescope along tangent, and clamp instrument.	"2. Set disc to division 60 on graduated scale.
"3. Look up in table first tangential angle for a 60 chain curve = 0°.28'.39".	"3. Direct telescope along tangent line, set needle to zero on dial and clamp instrument.
"4. Set vernier to read this angle by turning tangent screw. The telescope will then point to the first peg in the curve.	"4. Bring needle to division 1 on dial by turning tangent screw. The telescope will then point to the first peg in the curve.
"5. Look up in table second tangential angle = 0°.57'.18".	"5. Bring needle to division 2 on dial by turning tangent screw. The telescope will then point to the second peg in the curve.
"6. Set vernier to read this angle by turning tangent screw. The telescope will then point to the second peg in the curve.	"6. Bring needle to division 3 on dial by turning tangent screw. The telescope will then point to the third peg in the curve."
"7. Look up in table third tangential angle = 1°.25'.57".	
"8. Set vernier to read this angle by turning tangent screw. The telescope will then point to the third peg in the curve "and so on."	

The following are the directions given for use of the curve-ranger:—Having set up the instrument at the commencement of the curve A (Fig. 142O), move the disc *a* (Fig. 142N) along the graduated scale *b*, until the setting-index *c* fixed to the disc coincides with the division on the scale corresponding to the number of chains radius in the curve.

Thus if the curve to be set out is of 60 chains radius, move the disc *a* along the scale *b* until the edge of the setting-index *c* is coincident with division marked 60.

Now direct the telescope along the tangent to the curve A B, and bring the needle to the zero of the dial *d*, clamping both the clamps *e* and *f*. Perfect the bisection of the cross hairs in the diaphragm of the telescope with the pole at B by turning the tangent screw *g*. If the curve bends to the right as in the figure, turn the tangent screw *h* until the needle indicates 99 on the dial. In this position the telescope will point along the chord line A C, along which measure a chord of 1 chain. C will then be the first peg in a curve of 60 chains radius.

To obtain the second tangential angle, again turn the tangent screw *h* in the same direction until the needle points to division 98 on the dial. The telescope will then have described the second tangential angle, and will point along the chord A D. To obtain D, measure the chord line C D intersecting the line of sight, A D in D. This determines the second point, and so on a considerable number of points can be easily set out.

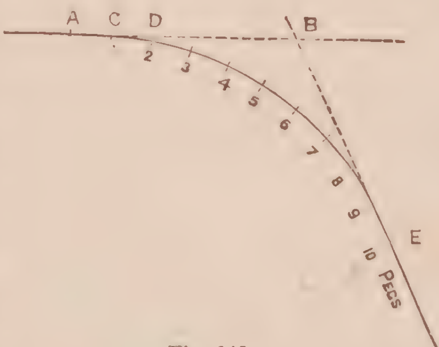


Fig. 142o.

If the curve bends to the left, the needle, instead of pointing to 99, 98, 97, &c., should be made to point to 1, 2, 3, &c., divisions on the dial, by turning the tangent screw *h* the reverse way.

The operation of ranging a new tangent is equally simple. Suppose it is required to set out a new tangent at peg 10, as in the above figure. The needle, when the telescope was pointing to peg 10, from the position A, indicated 90 on the dial, or 10 divisions from the zero, the dial face being divided into 100 equal parts.

Remove the instrument from A to E, peg 10, and there set it up, still pointing in the direction that the curve is being set out.

Transit the telescope, directing it to A, and bring the needle to division 10 on the dial, clamping the two clamps *e* and *f*. Turn the tangent screw *h* until the needle, passing over 10 divisions, indicates zero on the dial.

Now transit the telescope into its former position, when it will point along the tangent to the curve, and the curve may be

continued in either direction, to the right or left, as described above.

The limits of the graduation on scale *b* are from 50 to 100 chains radius, but curves of smaller or larger radius may be set out by the following simple method :—

Say radius of curve 25 chains. Set index *c* to division 50 on scale; and for tangential angles read 2, 4, 6, &c., on dial.

For a curve of larger radius, say 200 chains, set index *c* to division 100 on scale *b*, and read the dot between zero and division 1 for the first tangential angle, and division 1 for the second tangential angle, and so on, the dots being odd numbers, and the divisions even.

The price of the instrument, fitted to new or old theodolites, ranges from £7 7s. to £10 10s.

Stanley's Ray-Shade.—This (Fig. 142P) is an ingenious combination. The accepted necessity for a ray-shade in levels is made the opportunity for utilising it for other and useful purposes, especially for cross-section work in hilly country. The ordinary ray-shade has two narrow slits opposite each other at 180°. A zero line is carried from one slit to a line on the ray-shade, fitting when the slits are quite horizontal. Sight through the slits at zero enables an approximate cross-level to be taken. The edge of the tube of the ray-shade is divided 20° on each side of the zero line to 2°, so as to take approximate lateral inclines of the surface of the land in levelling.

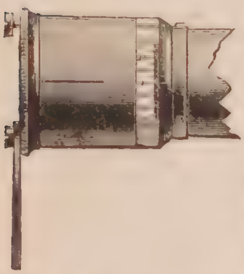


Fig. 142P.

This plan of cross-sighting was originally proposed by Gravatt.

Stanley's Improved Plane-Table. On page 63 (Figs. 114 and 115), I have described the *modus operandi* of the plane table, an instrument too little called into requisition, especially in contouring, and I here introduce a very complete instrument, adapted for all purposes. The drawing surface of this table (Fig. 142Q) consists of a loose panel which stretches the sheet of paper by pressing it into its frame, where it is afterwards held by a pair of ledges, which fit at their ends into long slots. The board is mounted upon a firmly-braced tripod-stand, as illustrated in Fig. 142R. The head of the tripod-stand is secured to the board with a central screw (not shown), which permits the board to be set in any direction, it being the rule that the edge w (Fig. 142Q) should always take a north to south direction. Three screws, *s s s* (Fig. 142R), at the corner of the triangular head, can be raised or lowered by milled heads from the under side. These screws permit about 15 deg. of adjustment to the

table without any unsteadiness, as the centre-screw clamps the table finally hard down upon them when all adjustments are made. A small trough form of magnetic compass *a* is placed upon the rule to strike the magnetic to south line, to which all angles are referred in transposing the work of the plane table.

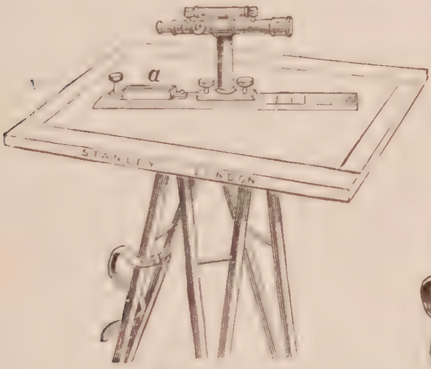


Fig. 142Q.

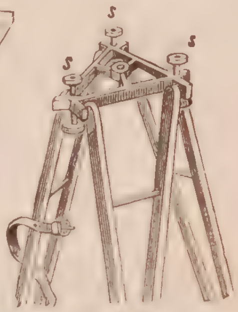


Fig. 142R.

The diaphragm of the telescope is provided with a platino-iridium point fixed vertically at the mutual focus of the object glass and the eye-piece.

Johnson's Improved Tripod-Head.—The illustrations (Figs. 142S and 142T) will sufficiently explain the principle of con-

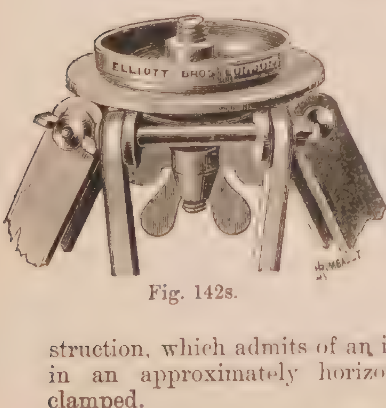


Fig. 142S.

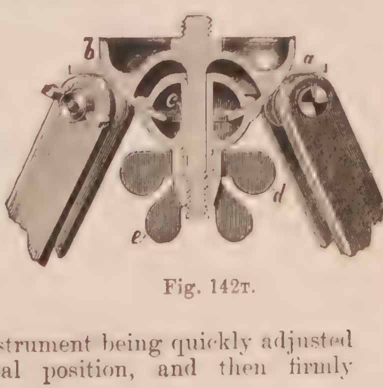


Fig. 142T.

struction, which admits of an instrument being quickly adjusted in an approximately horizontal position, and then firmly clamped.

The instrument, being attached to screw on *b*, is set approximately level by moving the tripod in the usual manner; release

the clamping nut *d*, and the sockets *b c* will then be free to move in any direction, and can be fixed in any position by again screwing up nut *d*. The upper plate *b* may be turned in azimuth by releasing the nut *e*, which leaves the hemispherical surface *b* free to move around the concave part *a* of the tripod-head.

This form of head, mounted on a framed stand of special construction, may be used to great advantage with an ordinary dumpy level, particularly on embankments, where it is difficult to find a level space for the legs of the tripod, as the movement of the sockets compensates the difference of level of the legs and so prevents undue straining of the parallel plate-screws; and these remarks apply equally with regards to theodolites, especially those used for mountain work. For plane tables, also, this form of head is a valuable improvement.

Price, complete with special framed tripod-stand, for plane tables and small levels, £5 5s.

Erskine's Altazimuth Theodolite.—Notwithstanding the high appreciation in which I hold the various instruments referred to in the foregoing pages, after a quarter of a century's experience with them under varied circumstances, I am bound to admit that Erskine's altazimuth, an instrument recently brought out, supplies in my judgment a long-felt want. It is at once a theodolite, a level, and a clinometer, and is comprised in so small a space as to render it available anywhere and under any circumstances.

Fig. 142U fairly illustrates the instrument, which consists of an ordinary vernier and limb, properly encased, upon which two substantial brackets carry the horizontal axis, also encased in (what may be termed) an enclosed collar. On the left is the vertical circle ($\frac{7}{16}$ inch wide), also encased, with the divisions marked upon the edge; whilst on the right hand side is the telescope, duly adjusted to the vertical circle. Over and above these is the compass, with its complement of right-angle levels for adjustment.

The weight of this beautiful little instrument is only 4 lbs., or with the tripod stand 8 lbs. The latter is made in the form known as the "open-lath" (similar to a camera stand), but by an ingenious arrangement the joints, instead of being folded are clipped with a screw adjustment, so that the lower leg may slide within the upper frame and be clamped at pleasure, especially in side-lying ground.

Another feature in this instrument is the provision of a reflector, to be attached to the object end of the telescope, for use at night (or especially in mining), consisting of a bulb of silver so arranged by an arm that it can be brought into the centre of the field, and thus reflect rays of light into the telescope.

I have recommended Messrs. Cary, Porter & Co. to improve

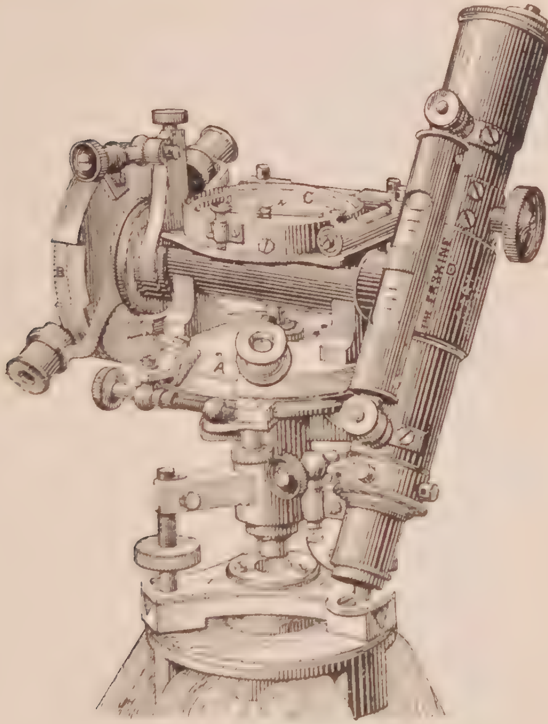


Fig. 142U.

the instrument by a special extra clamping arrangement, whereby its efficacy for levelling operations may be secured.

The price of the instrument complete is about £23.

Cary's Rack Adjustment to Eye-piece.—This ingenious arrangement—shown in Fig. 142V—entirely obviates the necessity of pulling out the eye-piece. In focussing the instrument, by a rack and pinion motion, the webs may be clearly defined with greater facility and without any risk to the diaphragm. This arrangement is applicable to every kind of instrument.

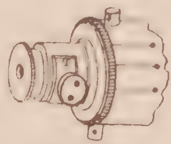


Fig. 142V.

CHAPTER IV.

TRIGONOMETRY REQUIRED IN SURVEYING

It is not intended in this chapter to do more than explain the general principles of trigonometry required in surveying.* Trigonometry is a science of great scope and interest, involving a vast amount of patient study if its higher branches are required; but for "Practical Surveying" it is quite possible, in such a chapter as the present—presupposing that the student has acquired from proper text books a moderate amount of elementary mathematics—to give a sufficiently general outline of trigonometry to enable the student to apply it thereto himself.

We do not pretend here to apply the science to every position required in surveying, but rather to enumerate the different definitions and theorems which the student should study and learn to apply where necessary.

Trigonometry has for its object the solution of triangles, and its application to surveying is the "art of measuring and computing the sides of plane triangles,† or of such whose sides are straight lines." Triangles consist of six parts, viz. three sides and three angles; and in every case in trigonometry three parts must be given in order to find the other three; and of those three given parts one must be a side, because with the same angles the sides may be greater or less in proportion.

We will commence with a few of the principal definitions of Euclid's geometry which bear upon trigonometry.

1. **Plane Surface.**—A plane surface, or plane, is a surface in which if any two points be taken, the straight line between them lies wholly in that surface.

2. **Plane Angle.**—A plane angle is the inclination of two lines to each other in a plane, which meet together, but are not in the same direction.

Note.—This definition includes angles formed by two curved

* The word trigonometry is derived from two Greek words, τριγωνον (trigo-non), *a triangle*, and μετρεω (met-re-o), *measure*.

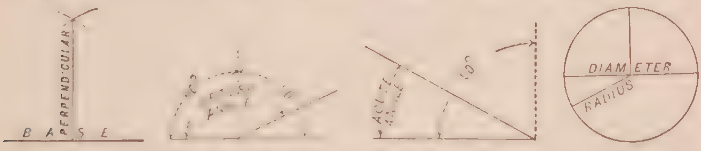
† "Plane Trigonometry" is the science which deals with straight lines, as compared with "Spherical Trigonometry," which involves the consideration of curved figures.

lines, or by a curve and a straight line, as well as angles formed by two straight lines.

3 Plane Rectilineal Angle. A plane rectilineal angle is the inclination of two straight lines to one another, which meet together, but are not in the same straight line.

Note.—When an angle is simply spoken of, a plane rectilineal angle is always meant.

4. Perpendicular.—When a straight line standing on another straight line makes the adjacent angles equal to one another,



4 5 6 9

each of these angles is called a right angle, and the straight lines are said to be perpendicular to each other.

5. Obtuse Angle.—An obtuse angle is greater than a right angle.

6. Acute Angle.—An acute angle is less than a right angle.

7 Circle.—A circle is a plane figure contained by one line, which is called the circumference, and is such that all lines drawn from a certain point within the figure to the circumference are equal to one another.

8. Centre of Circle.—And this point is called the centre of the circle.

9. Diameter of Circle.—The diameter of a circle is a straight line drawn through the centre, and terminated both ways by the circumference.

Note.—The radius of a circle is a straight line drawn from the centre to the circumference.

10. Semi-circle.—A semi-circle is a figure contained by a diameter, and the part of the circumference cut off by the diameter.

11. Segment of Circle.—A segment of a circle is a figure contained by any straight line and a part of the circumference, which it cuts off.

12. Rectilineal Figures—Rectilineal figures are those which are contained by straight lines.

13. Trilateral Figures.—Trilateral figures or triangles by three straight lines.

14. Quadrilateral Figures.—Quadrilateral figures by four straight lines.

15. Multilateral Figures.—Multilateral figures, or polygons by more than four straight lines.

16. Equilateral Triangle.—Of three-sided figures, an equilateral triangle has three equal sides.

17. Isosceles Triangle.—An isosceles triangle is a triangle which has two sides equal.

SCALENE TRIANGLE

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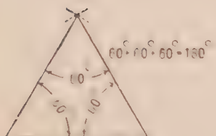

EQUILATERAL TRIANGLE

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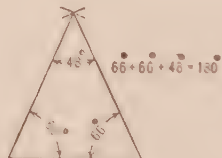

ISOSCELES TRIANGLE

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RIGHT ANGLED TRIANGLE

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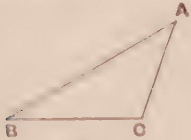
18. Scalene Triangle.—A scalene triangle has three unequal sides.

19. Right-angled Triangle.—A right-angled triangle is a triangle which has a right angle.

Note.—The side which subtends, that is, is opposite to the right angle, is called the hypotenuse.

20. Obtuse-angled Triangle.—An obtuse-angled triangle is a triangle which has an obtuse angle, and which by Def. 5 is greater than a right angle.



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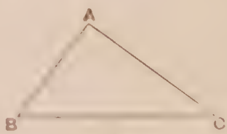

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21. Acute angled Triangle.—An acute-angled triangle is a triangle which has three acute angles.

Theorems.—1. If two triangles have two sides of the one equal to two sides of the other, each to each, and have likewise the angle contained by those sides equal to one another, they shall likewise have their bases or third sides equal, and the two triangles shall be equal, and their angles shall be equal each to each, namely those to which the equal sides are opposite.

2. The angles at the base of an isosceles triangle, A B C and A C B,

are equal to one another: and if the equal sides be produced the angles on the other side of the base, D B C and B C E, shall be equal to one another.

3. If two triangles have two sides of the one equal to two sides of the other, each to each, and have likewise their bases equal;

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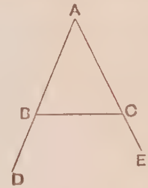

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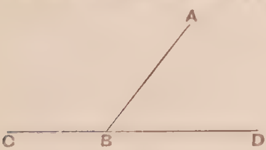
the angle which is contained by the two sides of the one shall be equal to the angle which is contained by the two sides equal to them of the other.

4. The angles which one straight line makes with another straight line on one side of it either are two right angles or are together equal to two right angles.

5. If at a point in a straight line, A B, two other straight lines, C B and B D, upon the opposite sides of it, make the adjacent angles



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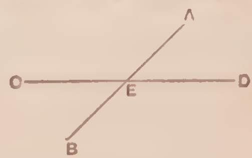

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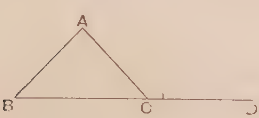
together equal to two right angles, these two straight lines, C B and B D, shall be in one and the same line.

6. If two straight lines cut one another, the vertically opposite angles shall be equal.

7. If one side of a triangle, B C, be produced to D, the exterior angle, A C D, is greater than either of the interior opposite angles, C A B and A B C.



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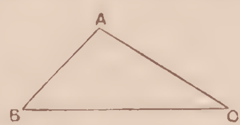

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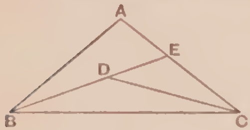
8. Any two angles of a triangle are together less than two right angles.

9. If one side of a triangle, A C, be greater than a second, A B, the angle, A B C, opposite the first must be greater than that opposite the second, A C B.

10. If one angle of a triangle be greater than a second, the side opposite the first must be greater than that opposite the second.

11. Any two sides of a triangle are together greater than the third side.

12. If, from the ends of the side of a triangle, C and B, there be



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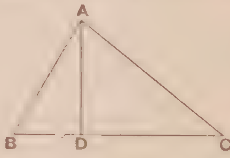

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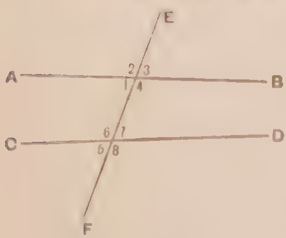
drawn two straight lines, B E and C D, to a point D, within the triangle, then B D and C D will be together less than the other sides, B A and A C, of the triangle, but will contain a greater angle, B D C.

13. Every straight line, A D, drawn from the vertex of a triangle to a point D within the base, is less than the greater of the two sides, A C, or than either, if they be equal.

Theory of Parallel Lines.—Hamblin Smith has very properly detached the propositions, in which Euclid treats of parallel lines, from those which precede and follow them in the first book, in order that the student may have a clearer notion of the difficulties attending this division of the subject. It is necessary here to explain some of the technical terms used.

14. If the straight line E F cut two other straight lines A B, C D, it makes with those lines eight angles, to which particular names



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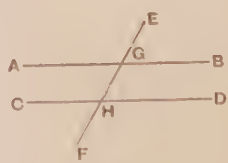

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are given. Thus the angles numbered 1, 4, 6, 7 are called the *interior* angles; and 2, 3, 5, 8 are called the *exterior* angles; 1 and 7, and 4 and 6, are called *alternate* angles; and the pairs of

angles, 1 and 5, 2 and 6, 4 and 8, 3 and 7 are called the *corresponding* angles.

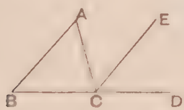
The angles 1, 4, 6, and 7 are equal to four right angles

15. If a straight line, E F, falling upon two other straight lines, A B and C D, make the alternate angles equal to one another, then the two straight lines must be parallel.

16. If a straight line fall upon two parallel straight lines, it makes the two interior angles upon the same side together equal to two right angles, and also the alternate angles equal to one another, and also the exterior angle equal to the interior and opposite upon the same side.

17. Straight lines which are parallel to the same straight line are parallel to one another.

18. If a side of any triangle B C be produced to D, the exterior angle is equal to the two interior and opposite angles, and the



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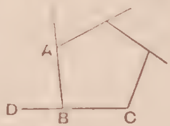

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three interior angles of every triangle are together equal to two right angles.

19. The exterior angles of any convex rectilinear figure, made by producing each of its sides in succession, are together equal to four right angles.

Now one of the most essential things to be understood with regard to angular measurement is the circle and its various divisions. A circle is divided into 360 equal parts or degrees, each degree into 60 minutes, and each minute into 60 seconds. The

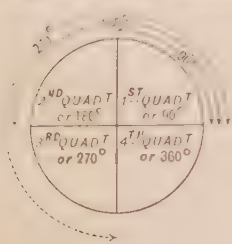


Fig. 143.

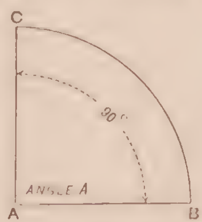


Fig. 144.

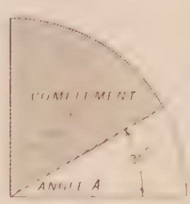


Fig. 145

following symbols are used to denote these divisions and sub-divisions: degrees (°), minutes (′), and seconds (″), so that 85 degrees, 27 minutes, and 13 seconds would be shown thus: 85° 27′ 13″.

The circle (Fig. 143) is divided into four quadrants of 90 degrees each, and by Definition 4 page 101) each of these is a right angle.

In trigonometry it is usual to consider the radius of a quadrant as unity, and as a line identical with the horizontal arm of the quadrant moves in an upward direction towards the vertical arm A C, Fig. 144, so the angle formed by this line produces certain functions which, for simplicity, are considered in the terms of the angle so formed, usually called the angle A. Thus Fig. 145 shows the angle A equal to 30 deg.; Fig. 146, the angle A equal to 45 deg.;

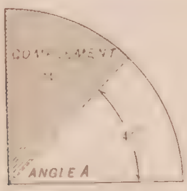


Fig. 146.

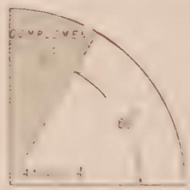


Fig. 147.

Fig. 147, the angle A equal to 60 deg.; and so a diagram may be constructed to represent an angle which is any fractional part of 90 deg.

It may be well here to introduce and explain the trigonometrical canon or diagram (Fig. 148), which shows the different trigonometrical functions in terms of the angle A to the radius = 1.

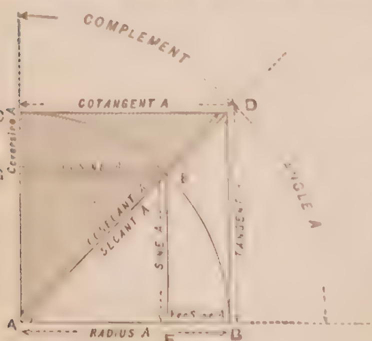


Fig. 148.

Now here, for simple illustration, I have taken the angle A as 45 deg.

The trigonometrical functions of the angle A are as follows: The SINE, CO-SINE, TANGENT, CO-TANGENT, SECANT, and CO-SECANT, with the VERSINE and CO-VERSINE, but the two latter do not enter largely into the consideration of the solution of triangles.

Now Fig. 149, illustrating the functions of an angle of 30 deg., shows by the strong lines certain positive functions of that angle, such as the sine, secant, and tangent; whilst the extended dotted lines, and dotted lines, show the complementary functions of the same angle, as the co-sine, co-secant, and co-tangent.

Here I should explain that the * complement of an angle is equal to its difference from 90 deg., so that 60 deg. is the complement of 30 deg.

The supplement of an angle is equal to its difference from 180 deg., so that the supplement of 30 deg. is 150 deg.

By referring to Figs. 149 and 150 it will be seen that in the former case the sine, secant, and tangent are much less than the co-sine, co-secant, and co-tangent (which are shown by dotted lines) by reason of the angle being small; whilst in Fig. 150 it will be seen that the sine, secant, and tangent are greater than are the co-sine, co-secant, and co-tangent; and going back to Fig. 148, we have the sine equal to the co-sine, the tangent equal to the co-tangent, and the secant equal to the co-secant.

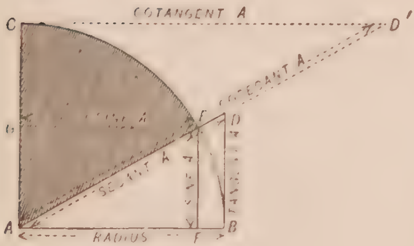


Fig. 149.

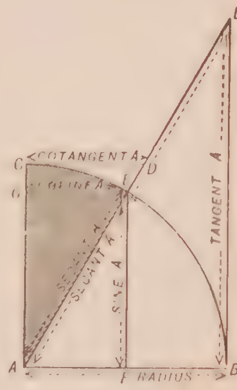


Fig. 150.

From the foregoing it will be seen that :—

Trigonometrical Ratios or Functions.—1. *Sine.*—The sine of an arc is a perpendicular let fall from the extremity of one radius to the other, as E F (Figs. 148, 149, and 150).

2. *Tangent.*—The tangent is a perpendicular line drawn from the extremity of the radius to meet the other produced, as B D.

3. *Secant.*—The secant is that radius which forms the angle produced until it meets the tangent, as A D.

4. *Cosine.*—The cosine is a line drawn parallel to that part of the radius between its centre and the foot of the sine.

5. *Cotangent.*—The cotangent is a horizontal line, commencing at the termination of the quadrant, and terminating on the

* The difference between an acute angle and a right angle is called its complement (*i.e.* the angle lacking to complete or fill up the right angle).

radius A E produced, in D (Fig. 148), D' (Fig. 149), and D (Fig. 150).

6. *Cosecant.*—The cosecant is one of the radii produced until it intersects the cotangent in D (Fig. 148), and D' (Fig. 149 and 150).

7. *Versed Sine.*—The versed sine is that portion of one of the radii between the foot of the sine and the arc as F B.

8. *Coversed Sine.*—The coversed sine is that portion of the perpendicular between the cosine and the quadrant, as G C.

9. *Chord.*—The chord of an arc is a line joining the extremities of the arc.

I should like here to explain what may appear to be an anomaly, viz. why the lines G E (cos A), C D' (cot A), and A D' (cosec A) (Fig. 149), should be the complementary to the functions of the angle A. But I hope the following will elucidate the matter. We have found (page 91) that the complement of an angle is the angle lacking to complete or fill up the right angle; and by reference to Fig. 149 it will be seen that the line G E bears the same relation to the angle E A C as E F does to the angle A or E A B, consequently G E must be the sine of the angle E A C. Thus what is the sine of an angle (less than 90 deg.) is the cosine of the remaining angle or complement, and *vice versa*. The line C D' bears the same relation to the angle E A C as D B bears to the angle E A B, therefore what is the cotangent of the angle E A B is the tangent of the angle E A C; and the same equally applies to the secant and cosecant.

These trigonometrical functions are abbreviated as follows:—

Sin A	= The sine of the angle A.	
Cos A	= The cosine	do.
Tan A	= The tangent	do.
Cot A	= The cotangent	do.
Sec A	= The secant	do.
Cosec A	= The cosecant	do.
Vers A	= The versed sine	do.
Covers A	= The coversed sine	do.
Cho A	= The chord	do.

Relation of Hypotenuse to the other Sides of Right-angled Triangle.—Perhaps it may be better to refer to the 47th proposition of Euclid, which states the theorem: "In any right-angled triangle, the square which is described on the side subtending the right angle is equal to the sum of the squares described on the sides which contain the right angle" (Fig. 151).

By this proposition the sum of the squares on the sides A and B is equal to that on the side C; in other words, taking another form of a right-angled triangle, as Fig. 152—

Let A B = Hypotenuse.
A C = Base.
B C = Perpendicular.

Then—

$$\text{Hypotenuse} = \sqrt{\text{Base}^2 + \text{Perp.}^2}.$$
$$\text{Base} = \sqrt{\text{Hyp.}^2 - \text{Perp.}^2}.$$
$$\text{Perp.} = \sqrt{\text{Hyp.}^2 - \text{Base}^2}.$$

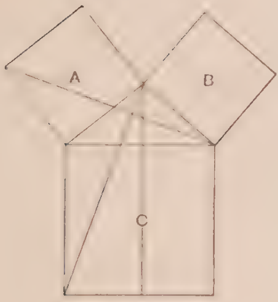


Fig. 151.

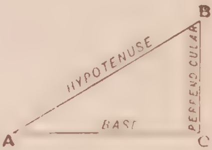


Fig. 152.

Now in the preceding descriptions of the various trigonometrical functions, I have shown that they all have reference to the angle A of the triangle B A C, a portion of the first quadrant (see Fig. 153),

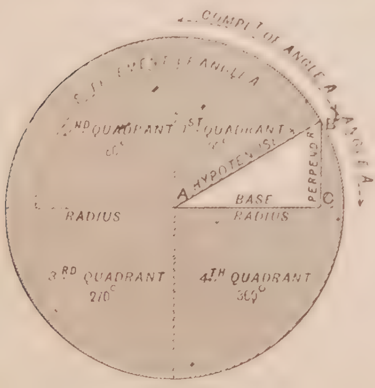


Fig. 153.

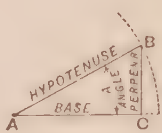


Fig. 154.

which is placed in the centre of the circle called the circle of reference.

We will now consider the functions of the angle A (B A C) in terms of the sides of the triangle A C B. We have seen (Figs. 149, 150) that the functions are the ratios borne by certain lines to the radius; and as a ratio or proportion may always be expressed in the form of a fraction, the functions may be obtained by dividing these lines by the radius. Now, so long as the angles of a triangle remain unchanged, the ratios of the sides of that triangle remain unchanged; hence, comparing Fig. 154 with Fig. 149 or Fig. 150, we are able to express the functions of the angle A in terms of the sides A B, B C, C A.

Thus:—

$$\text{Sin A} = \frac{\text{PERP}}{\text{HYP}} = \frac{\text{B C}}{\text{A B}}. \qquad \text{Cos A} = \frac{\text{BASE}}{\text{HYP}} = \frac{\text{A C}}{\text{A B}}.$$

$$\text{Tan A} = \frac{\text{PERP}}{\text{BASE}} = \frac{\text{B C}}{\text{A C}}. \qquad \text{Cot A} = \frac{\text{BASE}}{\text{PERP}} = \frac{\text{A C}}{\text{B C}}.$$

$$\text{Sec A} = \frac{\text{HYP}}{\text{BASE}} = \frac{\text{A B}}{\text{A C}}. \qquad \text{Cosec A} = \frac{\text{HYP}}{\text{PERP}} = \frac{\text{A B}}{\text{B C}}.$$

$$\text{Vers A} = \frac{\text{HYP} - \text{BASE}}{\text{HYP}} = \frac{\text{A B} - \text{A C}}{\text{A B}}.$$

$$\text{Covers A} = \frac{\text{HYP} - \text{PERP}}{\text{HYP}} = \frac{\text{A B} - \text{B C}}{\text{A B}}.$$

$$\text{B C} = \text{A B cos B}\,;\ \text{A C} = \text{A B sine B}\,;\ \text{A B} = \text{B C sec B}.$$
$$\text{B} = \text{complement of A} = 90 - \text{A}.$$
$$\text{A} + \text{B} + \text{C} = 180^\circ.$$

I may explain, by reference to Fig. 148, that the tangent, cotangent, secant, and cosecant appear therein much longer than the lines E F, A F, and E A, which correspond with the lines B C, A C, and A B in Figs. 153 and 154; and my reason for referring to it is to show that, as these lines are simply ratios to the radius, so what in Fig. 148 is the tangent of A, viz. $\frac{\text{B D}}{\text{A B}}$ is exactly the same ratio as $\frac{\text{B C}}{\text{A C}}$ in Figs. 153 and 154, or as follows :—

	Fig. 148.		Figs. 153 and 154.
Sin A	$= \dfrac{EF}{AE}$	$=$	$\dfrac{BC}{AB}$.
Cos A	$= \dfrac{GE}{AE} = \dfrac{AF}{AE}$	$=$	$\dfrac{AC}{AB}$.
Tan A	$= \dfrac{BD}{AB}$	$=$	$\dfrac{BC}{AC}$.
Cot A	$= \dfrac{CD}{AC}$	$=$	$\dfrac{AC}{BC}$.
Sec A	$= \dfrac{AD}{AB}$	$=$	$\dfrac{AB}{AC}$.
Cosec A	$= \dfrac{AD'}{AC}$	$=$	$\dfrac{AB}{BC}$.

A little reflection will serve to impress upon the mind the equality of these ratios under the two circumstances I have illustrated.

Cotangent of Greater or Less Angles.—Here the cotangent and cosecant in Fig. 149 appear extravagantly out of proportion with the condition of those in Figs. 153 and 154, but seeing that we are dealing with ratios of lines one towards another, and not the actual lengths of the lines themselves, there will I think be no difficulty in comprehending this fact.

I have thus in some detail endeavoured to clear up a difficulty that appears to have presented itself to many students with regard to the relations of these functions, and having done so, I now proceed to consider the practical application of these ratios to the solution of triangles, for which purpose I shall abandon the more complicated reference letters, and, as illustrated by Fig. 155, shall refer to each side as *a*, *b*, or *c*, and the angles as A, B, or C. C being the right angle, *c* is the hypotenuse, and *b* is the side adjacent to the angle considered. The angle B is the complement of A, since two acute angles in a right-angled triangle must be always equal to one right angle (for all the angles of *every* triangle equal *two* right angles).

Fig. 155.

Hence, with the altered lettering, we have a new list of functions:—

$$\text{Sin A} = \frac{a}{c} \qquad \text{Cos A} = \frac{b}{c}$$

$$\text{Tan A} = \frac{a}{b} \qquad \text{Cot A} = \frac{b}{a}$$

$$\text{Sec A} = \frac{c}{b} \qquad \text{Cosec A} = \frac{c}{a}$$

If we know the numerical value of any one of these ratios we can find A. In other words, if the ratio between any two sides of a right-angled triangle is given we can define all the angles.

Now the relations of trigonometrical ratios to one another (since the square of the hypotenuse of a right-angled triangle is equal to the sum of the squares of the two sides) are as follows:—

$$\text{Since } a^2 + b^2 = c^2.$$

$$\text{dividing by } c^2, \frac{a^2}{c^2} + \frac{b^2}{c^2} = \frac{c^2}{c^2} = 1;$$

$$\text{or } \sin^2 A + \cos^2 A = 1 \quad . \quad . \quad . \quad . \quad (1).$$

Dividing the first equation by b^2, we get $\left(\frac{a}{b}\right)^2 + 1 = \left(\frac{c}{b}\right)^2$; or reversing the order. $\sec^2 A = 1 + \tan^2 A. \quad . \quad . \quad . \quad . \quad (2).$

Dividing the same by a^2, we get $1 + \left(\frac{b}{a}\right)^2 = \left(\frac{c}{a}\right)^2$; or reversing the order as before, $\operatorname{cosec}^2 A = 1 + \cot^2 A. \quad . \quad . \quad . \quad . \quad (3).$

$$\text{Since } \frac{a}{b} \cdot \frac{b}{a} = 1, \tan A \cot A = 1. \quad . \quad . \quad . \quad . \quad (4).$$

$$\text{Again } \tan A = \frac{a}{b} = \frac{\frac{a}{c}}{\frac{b}{c}}, \therefore \tan A = \frac{\sin A}{\cos A} \quad . \quad . \quad . \quad . \quad (6).$$

$$\text{Again } \cot A = \frac{b}{a} = \frac{1}{\frac{a}{b}}, \therefore \cot A = \frac{1}{\tan A} \quad . \quad . \quad . \quad . \quad (7).$$

$$\text{Again } \cot A = \frac{b}{a} = \frac{\frac{b}{c}}{\frac{a}{c}}, \therefore \cot A = \frac{\cos A}{\sin A} \quad . \quad . \quad . \quad . \quad (8).$$

$$\text{Again } \sec A = \frac{c}{b} = \frac{1}{\frac{b}{c}}, \therefore \sec A = \frac{1}{\cos A} \quad . \quad . \quad . \quad . \quad (9).$$

$$\text{Again } \operatorname{cosec} A = \frac{c}{a} = \frac{1}{\frac{a}{c}}, \therefore \operatorname{cosec} A = \frac{1}{\sin A} \quad . \quad . \quad . \quad . \quad (10).$$

$$\text{Vers } A = 1 - \cos A, \text{ and covers } A = 1 - \sin A. \quad . \quad . \quad . \quad . \quad (11).$$

The foregoing equations enable us to find the value of any function in terms of any other functions, thus :—

Sin A in Terms of Cos A.—Let it be required to express sin A in terms of cos A and *vice versâ*. By equation(1) we have seen that

$$\text{Sin}^2 A + \cos^2 A = 1. \quad \text{Consequently}$$

$$\text{Sin } A = \sqrt{1 - \cos^2 A} \; . \; . \; . \; . \; (12).$$

$$\text{Cos } A = \sqrt{1 - \sin^2 A} \; . \; . \; . \; . \; (13).$$

Tan A in Terms of Sin A.—Let it be required to express tan A in terms of sin A.

$\text{Tan } A = \dfrac{\sin A}{\cos A}$ (6), and in (13) we have seen cos A $= \sqrt{1 - \sin^2 A}$,

$$\therefore \text{Tan } A = \frac{\sin A}{\sqrt{1 - \sin^2 A}} \; . \; . \; . \; . \; (14).$$

Tan A in Terms of Cos A.—Let it be required to express tan A in terms of cos A. Since by (6), tan A $= \dfrac{\sin A}{\cos A}$; and, by (12), sin A $= \sqrt{1 - \cos^2 A}$.

$$\therefore \text{Tan } A = \frac{\sqrt{1 - \cos^2 A}}{\cos A.} \; . \; . \; . \; (15).$$

Cos A in Terms of Tan A.—Let it be required to express cos A in terms of tan A.

$$\text{By equation (9) } \cos A = \frac{1}{\sec A}.$$

$$\text{But by equation (2) } \sec^2 A = 1 + \tan^2 A,$$

$$\therefore \sec A = \sqrt{1 + \tan^2 A},$$

$$\text{and therefore } \cos A = \frac{1}{\sqrt{1 + \tan^2 A}} \; . \; . \; . \; . \; . \; (16).$$

Sin A in Terms of Tan A.—Let it be required to express sin A in terms of tan A. Now sin A = cos A · tan A, therefore by preceding article

$$\text{Sin } A = \frac{\tan A}{\sqrt{1 + \tan^2 A}} \; . \; . \; . \; . \; . \; (17).$$

Sin A in Terms of Sec A.—Let it be required to express sin A in terms of sec A.

Since $\sin^2 A = 1 - \cos^2 A$; substituting for $\cos A$, $\sin^2 A = 1 - \dfrac{1}{\sec^2 A}$; $\therefore$ reducing to a common denominator and taking the square root we have $\sin A = \dfrac{\sqrt{\sec^2 A - 1}}{\sec A}$ . . (18)

Cos A in Terms of Cosec A. —To express $\cos A$ in terms of $\operatorname{cosec} A$.

By (8) $\cot A = \dfrac{\cos A}{\sin A}$; $\therefore \cos A = \cot A \sin A$,

and $\therefore \cos A = \dfrac{\sqrt{\operatorname{cosec}^2 A - 1}}{\operatorname{cosec} A}$ . . . . (19).

Cot A in Terms of Sec A.—To express $\cot A$ in terms of $\sec A$

$$\text{Cot } A = \frac{1}{\tan A} = \frac{1}{\sqrt{\sec^2 A - 1}} \quad . . . . (20).$$

To express cosec A in terms of sec A.

$$\text{Cosec } A = \frac{1}{\sin A}\ (10) = \frac{1}{\sqrt{1 - \cos^2 A}}\ (12)$$

$$= \frac{1}{\sqrt{1 - \dfrac{1}{\sec^2 A}}} = \frac{1}{\sqrt{\dfrac{\sec^2 A - 1}{\sec^2 A}}} = \frac{1}{\dfrac{\sqrt{\sec^2 A - 1}}{\sec A}},$$

and therefore $\operatorname{cosec} A = \dfrac{\sec A}{\sqrt{\sec^2 A - 1}}$ . . . . (21).

To express sin A in terms of tan A Since $\sin A = \tan A . \cos A$

$= \tan A \dfrac{1}{\sqrt{1 + \tan^2 A}}$, $\therefore \sin. A = \dfrac{\tan A}{\sqrt{1 + \tan^2 A}}$ (22).

Following on we arrive at these results :—

$$\text{Tan } A = \sqrt{\sec^2 A - 1} \quad . . (2) . . (23).$$

$$\text{Sec } A = \sqrt{1 + \tan^2 A} \quad . . . . (24).$$

$$\text{Cot } A = \sqrt{\operatorname{cosec}^2 A - 1} \quad . (3) . (25).$$

$$\text{Cosec } A = \sqrt{1 + \cot^2 A} \quad . . . . (26).$$

It is very desirable to learn to express every function in terms of every other function, as by means of working these out in detail the mind is impressed, and the relations of one function to another will become familiar.

Complemental Angles.—It has been shown that the complement of an angle (*i.e.* of an acute angle) is the difference between it and

a right angle, or commonly called its "defect." Thus if the angle A be 30 deg. the complement will be 90 deg. − 30 deg. = 60 deg. Again, if the angle A = 56 deg. 16 min. then its complement will be 90 deg. − 56 deg. 16 min. = 33 deg. 44 min.

Now, I have endeavoured to explain by the trigonometrical canon the various functions, which are as follows:—To the lines which are the trigonometrical functions of the arc correspond certain ratios which are the trigonometrical functions of the angles which the arc subtends.

In Fig. 156 I have shown the angle A = 30 deg., the sine of this angle is B C whilst the cosine is B D, and the angle B A E is its complement. Now the sine is that line lying within the arc which is perpendicular to the base, which in the angle B A C is B C. But if B D is perpendicular to E A, and since A D is the cosine of the angle B A E, and A D = B C, therefore the cosine of the angle B A E or the complement of A equals the sine of A.

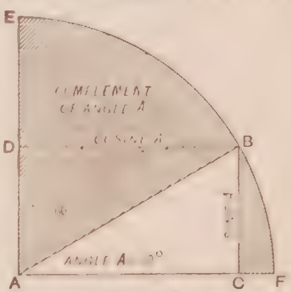


Fig. 156.

Thus we may deduce the following facts:—

The cosine of an angle is the sine of its complement.

The cotangent of an angle is the tangent of its complement.

The cosecant of an angle is the secant of its complement, &c.

So far so good, referring to the diagram in Fig. 156; but I want to impress on the student that in trigonometry we have in practice to do without the canon and consider only the triangle.

Now, as a simple illustration, we will take the case of a right-angled triangle as Fig. 156, the angle B A C of which is 30 deg. We know B C A to be 90 deg., thereupon the angle A B C will be 90 deg. − 30 deg. = 60 deg., which is the complement.

If, as we have seen, sin A (Fig. 152) is $\frac{\text{PERP}}{\text{HYP}}$ or $\frac{BC}{AB}$, and cos A is $\frac{\text{BASE}}{\text{HYP}}$ or $\frac{AC}{AB}$; from the foregoing it will not be difficult to realise that in a triangle the functions of the angle and its complement are in the inverse ratio. To better illustrate this, somewhat anticipating the practical application of the foregoing, I may say that the value of the

Nat sin 30 deg. = ·50000. Nat sin 60 deg. = ·86603.
Nat cos 30 deg. = ·86603. Nat cos 60 deg. = ·50000.

Supplemental Angles.—*The supplement of an angle is the difference between it and two right angles.*

Thus two right angles are equal to 180 deg., consequently if the angle A = 30° the supplement will be 180° − 30° = 150°; or, if the angle A is 29° 16′, then the supplement will be 180° − 29° 16′ = 150° 44′.

The sine of an angle is equal to the sine of its supplement.

In Fig. 157, C′ A B′ is the supplement of the angle F A B′, and is equal to F A B, and also C B is equal to C′ B′, and therefore

$\frac{C' B'}{A B'} = \frac{C B}{A B}$, but $\frac{C B}{A B}$ is the sine of the angle A, and $\frac{C' B'}{A B'}$ is the sine of the supplement, therefore they are equal.

The cosine of an angle is equal to the cosine of its supplement, but of opposite sign.

Use of the + and − Signs.—Before proceeding to reason this out it is necessary to speak of the conventional signs, plus and

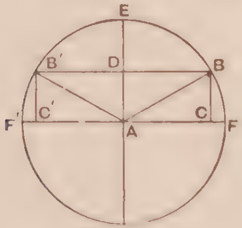


Fig. 157.

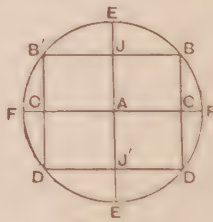


Fig. 158.

minus, used in trigonometry. As in Fig. 158, we may divide a circle into four quadrants, commencing with the first right-hand one above the horizontal or datum line F A F. With A as centre or origin, if a line revolving from the initial line A F forms any angle less than 90 deg., it is treated, as has been explained, as the angle A proper; but if this revolving line has passed through 90 deg. and makes therefore an angle greater than 90 deg. with the initial line, the supplement of this angle is less than 90 deg., and is the angle to be considered.

The definitions of trigonometrical functions are perfectly general, and therefore applicable to arcs of any magnitude. If an arc be greater than a quadrant some of the lines which have been defined as the trigonometrical functions lie to the left of the vertical diameter E A E′, and some below the horizontal diameter F′ A F. In order to take account of these variations of position, mathematicians have been led to adopt the following conventional signs as to the plus and minus, which enable us at the same time

to represent the position as well as the magnitude of the line in question. Referring to Fig. 158 the lines F F and E E′ represent the horizontal and vertical diameter working around the centre or origin A. Now all lines measured on F′ F, provided they are to the right of A, are positive or +, and those to the left are negative or −. Similarly, every line measured on E′ A E, if it lie above F′ A F is positive, and negative if below that line. Thus A C is +, because it lies to the right of A; B C is + because it is measured by its equal J A, which lies above A; and upon the same principle A C′ and C′ D′ are both −; B′ C′ is +, and C D is −.

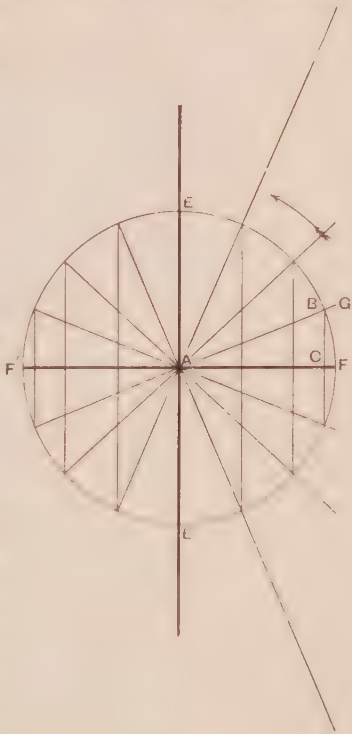


Fig. 159.

Referring to Fig. 159, if we trace the value of the sine in its progress round the circle from right to left, in direction of the arrow, we shall find that as the revolving line progresses through the four quadrants that in the first and second the sine is positive, whilst in the third and fourth it is negative. Now it has been established that—

1st. Any line drawn parallel to F′ A F from left to right is to be positive, and consequently any line drawn parallel to F A F′ from right to left is to be negative.

2nd. Any line drawn parallel to E′ A E in the direction from E′ to E upwards is positive, and consequently any line drawn downwards in a direction parallel to E E′ is negative.

3rd. Any line drawn parallel to the revolving line in the direction of A B (Figs. 160, 161, 162, 163) is to be positive, and consequently any line drawn in the opposite direction is negative. The line A C is always positive.

We have previously seen that the following are some of the ratios.

$$\sin \text{BAC} = \frac{\text{CB}}{\text{AB}}; \quad \cos \text{BAC} = \frac{\text{AC}}{\text{AB}}; \quad \tan \text{BAC} = \frac{\text{BC}}{\text{AC}}.$$

Therefore, keeping in mind that in the first quadrant C B is positive, being drawn from C to B upwards, A C is positive because it is drawn from left to right, and A B is positive.

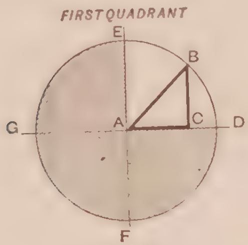


Fig. 160.

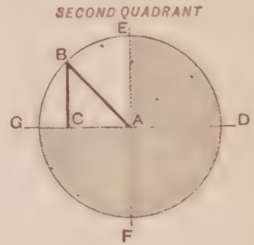


Fig. 161.

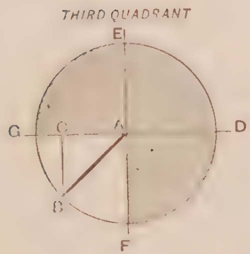


Fig. 162.

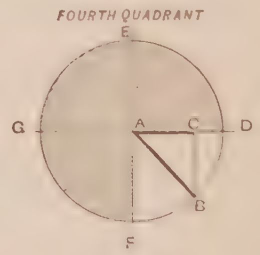


Fig. 163.

(1.) Thus if the angle A be anywhere within the first quadrant (Fig. 160).

$$\text{Sin A} = \frac{\text{C B}}{\text{A B}} \text{ is positive; } \cos \text{A} = \frac{\text{A C}}{\text{A B}} \text{ is positive; and } \tan \text{A} = \frac{\text{B C}}{\text{A C}} \text{ is positive.}$$

When the angle A lies in the second quadrant (Fig. 161) C B is positive, because from C to B is upward; A C is negative, because from A to C is towards the left, and A B is positive.

(2.) Thus for second quadrant

$$\text{Sin A} = \frac{\text{C B}}{\text{A B}} \text{ is positive; } \cos \text{A} = \frac{\text{A C}}{\text{A B}} \text{ is negative; and } \tan \text{A} = \frac{\text{C B}}{\text{A C}} \text{ is negative.}$$

(3.) In the third quadrant (Fig. 162) C B is negative, A C is negative, and A B is positive, consequently

Sin A $= \frac{BC}{AB}$ is negative; cos A $= \frac{AC}{AB}$ is negative; and **tan** A $= \frac{BC}{AC}$ is positive.

(4.) In the fourth quadrant (Fig. 163) B C is negative, A C is positive, A B is positive. Thus—

Sin A $= \frac{BC}{AB}$ is negative; cos A $= \frac{AC}{AB}$ is positive; and tan A $= \frac{BC}{AC}$ is negative.

From the foregoing we can now tabulate the results as follows:—

TABLE I.

	First Quadrant.	Second Quadrant.	Third Quadrant.	Fourth Quadrant.
Sine . .	+	+	—	—
Cosine . .	+	—	—	+
Tangent . .	+	—	+	—

NOTE.—The secant, cosecant, and cotangent of the angle A have the same sign as the sine, cosine, and tangent of the angle A.

Now to prove that "the cosine of an angle is equal to the cosine of its supplement, but of opposite sine." Referring to Fig. 157, the lines A C and A C′ are equal, but being in different quadrants, A C lies in a different direction to A C′, and thus they have different signs.

Therefore, having regard to sign, $\frac{AC}{AB} = -\frac{AC'}{AB'}$;

Now $\frac{AC}{AB} =$ cos A, and $\frac{AC'}{AB'}$, = cos of the supplement of A (viz. C A B′).

$$\therefore \text{Cos A} = -\cos(180° - A) \quad . \quad . \quad . \quad . \quad (27).$$

Relations of Lines to Functions of the Angle of Reference.—Before proceeding any further in the practical application

of the foregoing formulæ, I will speak of the relation the lines or functions of the arc bear to certain ratios, which are the trigonometrical functions of the angles which the arc subtends. They are as follows—

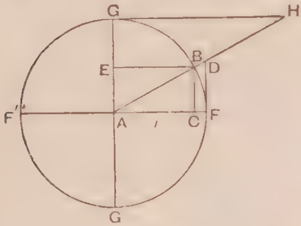


Fig. 164.

Definition—The sine, cosine, tangent, &c., of an angle at the centre of a circle is equal to the ratio of the sine, cosine, tangent, &c., of the corresponding arc to the radius of the circle.

The radius A F (Fig. 164) is denoted as r, and the angle H A F is denoted by A.

Then—

$$\text{Sin A} = \frac{\text{B C}}{r}; \ \cos \text{A} = \frac{\text{A C}}{r}; \ \tan \text{A} = \frac{\text{D F}}{r}; \ \sec \text{A} = \frac{\text{A D}}{r};$$

$$\cot \text{A} = \frac{\text{G H}}{r}; \ \text{cosec A} = \frac{\text{A H}}{r}; \ \text{vers A} = \frac{\text{C F}}{r}; \text{ and covers A} = \frac{\text{E G}}{r}.$$

Radius Unity.—In trigonometry the radius is commonly taken as representing unity, and for practical purposes, if the radius is divided into the length of any one of the lines representing functions, it will give the value of that function.

Basis of Formulæ for Tables of Sines, &c.—It is necessary now to briefly consider how the foregoing equations may be worked out, so as to be of practical value. This has been done by many eminent mathematicians in the form of tables of natural sines, cosines, &c. With such available, it would be a waste of time to undertake calculations for ourselves, and a set of such tables sufficient for the purpose of this work will be found in the Appendix (*post*, pp. 283 to 321). To illustrate the basis upon which such tables are prepared, I will select a few examples, as follows, for angles of 18 deg., 30 deg., 45 deg., and 60 deg. I will take that of 45 deg. first.

By the equation (1)— $\quad \text{Sin}^2 \text{A} + \cos^2 \text{A} = 1.$

$$\therefore \text{Sin}^2 45^\circ + \cos^2 45 = 1.$$

But since the complement of 45° is

$$90^\circ - 45^\circ = 45^\circ \therefore \sin 45^\circ = \cos 45^\circ, \text{ and } \sin^2 45^\circ = \cos^2 45^\circ.$$

$$\therefore 2 \sin^2 45^\circ = 1; \text{ and } 2 \cos^2 45^\circ = 1.$$

$$\therefore \ \sin {}^2 45° = \frac{1}{2}, \text{ and } \sin \ 45° \ \frac{1}{\sqrt{2}} = 0·70711;$$

Similarly, $\cos 45° = 0·70711$.

Again, by (6), $\tan A = \frac{\sin A}{\cos A}$,

$$\therefore \tan 45° = \frac{\sin 45°}{\cos 45°} = \frac{0·70711}{0·70711} = 1.$$

Then by (7) $\cot A = \frac{1}{\tan A}$,

$$\therefore \cot 45° = \frac{1}{\tan 45} = 1.$$

Similarly, by (9), $\sec A = \frac{1}{\cos A}$,

$$\therefore \sec 45° = \frac{1}{\cos 45} = \frac{1}{0·70711} = 1·41421.$$

And finally, (10), $\operatorname{cosec} A = \frac{1}{\sin A}$,

$$\therefore \operatorname{cosec} 45° = \frac{1}{\sin 45°} = \frac{1}{0·70711} = 1·41421.$$

Sines, &c, for 45 Degrees. The following is the result of the preceding investigations:—

Sin	45°	= 0·70711.
Cos	45°	= 0·70711.
Tan	45°	= 1·00000.
Cot	45°	= 1·00000.
Sec	45°	= 1·41421.
Cosec	45°	= 1·41421.

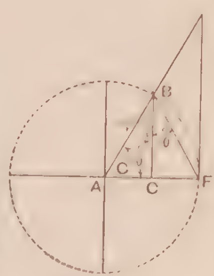


Fig. 165.

In the case of the angle of 60 deg., the revolving line forms a portion of an equilateral triangle, whereof A B, A F, and F B (Fig. 165), are equal sides, consequently the line B C, or sine, bisects the triangle; now the angle B A C = 60 deg. and the angle A B C = 30 deg., therefore as the length of the base A F is equal to that of the two other sides, then A C is half A F.

Sines, &c., for 60 Degrees.—Let B C be represented by x, A C by c, A B by $2c$—

$$\text{Then } x^2 = (2c)^2 - c^2 = 4c^2 - c^2 = 3c^2$$
$$\therefore \quad x = \sqrt{3} \cdot c$$

$$\text{And since } \sin 60^\circ = \sin \text{BAC} = \frac{\text{BC}}{\text{AB}} = \frac{\sqrt{3} \cdot c}{2c} = \frac{\sqrt{3}}{2} = \cdot 86603$$

$$\text{Again } \cos 60^\circ = \frac{\text{AC}}{\text{AB}} = \frac{c}{2c} = \frac{1}{2} = \cdot 50000$$

$$\text{And } \tan 60^\circ = \tan \text{BAC} = \frac{\text{BC}}{\text{AC}} = \frac{\sqrt{3 \cdot c^2}}{c} = \frac{\sqrt{3}}{1} = \sqrt{3} = 1 \cdot 7321$$

$$\text{Cot } 60^\circ = \cot \text{BAC} = \frac{1}{\tan 60^\circ} = \frac{1}{\sqrt{3}} = \cdot 57735$$

$$\text{Sec } 60^\circ = \sec \text{BAC} = \frac{1}{\cos 60^\circ} = \frac{1}{\frac{1}{2}} = 2 = 2 \cdot 0000$$

$$\text{Cosec } 60^\circ = \operatorname{cosec} \text{BAC} = \frac{1}{\sin 60^\circ} = \frac{2}{\sqrt{3}} = 1 \cdot 15470$$

Again, take the angle of 30 deg., when, because A C is half A F (Fig. 165), and the angle A B F, which is 60 deg., is bisected by B C, then A B C = F B C = ½ the angle A B F = 30 deg.

Thus

$$\text{Sin } 30^\circ = \sin \text{ABC} = \frac{\text{CA}}{\text{BA}} = \frac{c}{2c} = \frac{1}{2} = \cdot 50000$$

Sines, &c., for 30 Degrees.—

$$\text{Cos } 30^\circ = \cos \text{ABC} = \frac{\text{BC}}{\text{BA}} = \frac{\sqrt{3} \cdot c}{2c} = \frac{\sqrt{3}}{2} = \cdot 86603$$

$$\text{Tan } 30^\circ = \tan \text{ABC} = \frac{\text{CA}}{\text{CB}} = \frac{c}{\sqrt{3} \cdot c} = \frac{1}{\sqrt{3}} = \cdot 57735$$

$$\text{Cot } 30^\circ = \cot \text{ABC} = \frac{\text{BC}}{\text{CA}} = \frac{\sqrt{3} \cdot c}{c} = \sqrt{3} = 1 \cdot 7321$$

$$\text{Sec } 30^\circ = \sec \text{ABC} = \frac{\text{BA}}{\text{BC}} = \frac{2c}{\sqrt{3} \cdot c} = \frac{2}{\sqrt{3}} = 1 \cdot 15470$$

$$\text{Cosec } 30^\circ = \operatorname{cosec} \text{ABC} = \frac{\text{BA}}{\text{AC}} = \frac{2c}{c} = 2 = 2 \cdot 0000$$

Sines, &c., for 60 and 30 Degrees.—From the foregoing results we may tabulate the natural sines, &c., of the angle 60 and 30 degrees respectively, viz. :—

Sine of 60°	= ·86603.	Sine 30°	= ·50000.
Cos of 60°	= ·50000.	Cos 30°	= ·86603.
Tan of 60°	= 1·73210.	Tan 30°	= ·57735.
Cotan of 60°	= ·57735.	Cotan 30°	= 1·73210.
Sec of 60°	= 2·00000.	Sec 30°	= 1·15470.
Cosec of 60°	= 1·15470.	Cosec 30°	= 2·00000.

Thus it will be seen that the value of the sine of 60 deg. = cos 30 deg.; tan 60 deg. = cot 30 deg.; and sec 60 deg. = cosec 30 deg., and *vice versa*.

Now, take the angle 18 deg. as another example, of which it is required to find the sine, cosine, and tangent, &c.

Sines, &c., for 18 Degrees.—Let the angle B A C (Fig. 166) = 18 deg., drop the perpendicular B C, which produce to meet the circumference in B′, then it is evident that the angle B A B′ is twice the angle B A C, or 36 deg. B B′ is therefore one side of a decagon, inscribed in the circle: and therefore B B′ is equal to the greater segment of the radius cut in extreme and mean ratio (Euclid IV. 11), and therefore

$$BB'^2 = AF\,(AF - BB'),$$

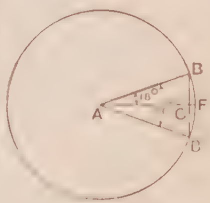


Fig. 166.

$$\text{and } \therefore BB' = AF \times \frac{\sqrt{5} - 1}{2}.$$

But $BC = \frac{1}{2} BB'$, therefore

$$\text{Sin } 18° = \frac{BB'}{2\,AF} = \frac{\sqrt{5} - 1}{4} = \cdot 30902$$

$$\text{Cos } 18° = \sqrt{1 - \sin^2 18°} = \frac{\sqrt{10 + 2\sqrt{5}}}{4} = \cdot 95105,$$

$$\text{Tan } 18° = \frac{\sqrt{5} - 1}{\sqrt{10 + 2\sqrt{5}}} = \cdot 32492,$$

$$\text{Cot } 18° = \frac{\sqrt{10 + 2\sqrt{5}}}{\sqrt{5} - 1} = 3\cdot 07768,$$

$$\text{Sec } 18^\circ = \frac{4}{\sqrt{10 + 2\sqrt{5}}} = 1{\cdot}05146,$$

$$\text{Cosec } 18^\circ = \frac{4}{\sqrt{5} - 1} = 3{\cdot}23607$$

From the foregoing we can now tabulate the following:—

Sin	18°	=	·30902.
Cos	18°	=	·95105.
Tan	18°	=	·32492.
Cot	18°	=	3·07768.
Sec	18°	=	1·05146.
Cosec	18°	=	3·23607.

As far as we have gone we have considered only angles less than 90 deg., but it is necessary to briefly investigate what happens when the revolving line A B (Figs. 160, 161, 162, 163) passes the first quadrant. We will take 120 deg., or 90 deg. + 30 deg. as the angle B A D. Now we are dealing with two right angles, consequently the angle B A D if deducted from 180 deg. will give us the value of B A G or 180 deg. — 120 deg. = 60 deg. = B A G.

Sines, &c., for 120 Degrees.—Therefore, sine 120 deg. $= \frac{\text{B C}}{\text{A B}}$ which referring to the equation on page 116 is equal to the sine of 60 deg.

Therefore, sin. 120 deg. = sin. 60 deg., and being in the second quadrant as we have seen in Table I. (page 119), it is of a positive character, whilst the cosine and tangent are negative.

Thus

$$\text{Sin } 120^\circ = \frac{\sqrt{3}}{2},$$

$$\text{Cos } 120^\circ = -\frac{1}{2}$$

$$\text{Tan } 120^\circ = -\sqrt{3}.$$

Sines, &c., for 225 Degrees.—Passing into the third quadrant, suppose it be required to find the sine, cosine, tangent, &c., of 225 deg.

Then 225 deg. — 180 deg. = 45 deg. = B A D (Fig. 148), and as in the third quadrant from the Table I. we have seen that the sine and cosine are negative whilst the tangent is positive.

Consequently

$$\text{Sin } 225° = -\frac{1}{\sqrt{2}}$$

$$\text{Cos } 225° = -\frac{1}{\sqrt{2}}$$

$$\text{Tan } 225° = 1$$

From the foregoing remarks we have seen the various functions of right angled triangles, and have been able to deduce certain formulæ which enable us to arrive at the numerical value of each. These values are what are termed natural sines, cosines, &c., and they are based upon the understanding that the radius is always unity, in other words they are relatively circumstanced to unity. Thus sin 45 deg. = 0·70711, but the tan 45 deg. and the cotan 45 deg. = 1 = radius. To illustrate my meaning.

Ratio of Radius.—Suppose the radius of a circle to be 40 ft., and a right angled triangle formed by the base, perpendicular and hypotenuse of an angle of 45 deg. as in Fig. 167. A F = A B = 40 ft., and it is required to know the length of B C; referring to the trigonometrical canon (Fig. 148), we find E F (which is the same as B C in Fig. 167) is the sine.

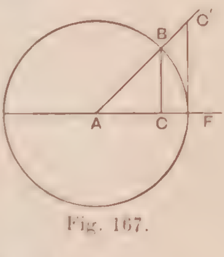


Fig. 167.

Therefore as we have seen that sin 45 deg. = 0·70711, then if we multiply 0·70711 by 40 we shall get the length B C = 28·28440 ft., so that 28·28440 represents the ratio of the radius 40 ft. just exactly as 0·70711 is the ratio of the radius of unity.

Again, if we want the length A C′ we know by our canon that A C′ is the secant (and also the cosecant of 45 deg.). Now our tables tell us that sec 45 deg. = 1·41421, therefore this multiplied by the radius or 40 feet gives us

1·41421 × 40 ft. = 56·56840 ft. = the length A C′.

Now we know the length B C but not that of A C, and A C is the cosine.

Therefore, A C = A B cos 45° = 40 × 0·70711 = 28·28440 ft.

At the risk of being considered irregular, if not too elementary, I have elected to illustrate the foregoing examples in a somewhat rule-of-thumb style, for this work does not profess to do more than seek, by as graphic a manner as possible, to bridge over many of the difficulties which the student has to encounter.

Solution of Right-angled Triangles.—All triangles consist of six parts, viz. three sides and three angles; and it is possible with

three of these, one part being at least a side, to find the others Referring back to Fig. 155, if we take the sides as represented by a, b, and c, and the angles by A, B, and C, with the following approximate lengths of each, $a = 21{\cdot}85$ feet, $b = 60$ feet, and $c = 64$ feet, we have the following results.

We have seen that $\frac{a}{b} = \tan A$, then $\tan A = \frac{a}{b} = \frac{21{\cdot}85}{60{\cdot}00}$ $= {\cdot}36416$, which by reference to a table of natural sines indicates that the angle $A = 20^\circ$. And since C is 90°, then $B = 90^\circ - 20^\circ = 70^\circ$.

Take $b = 60$ and $c = 64$. Then as $\frac{b}{c}$ is $\cos A$,

$$\therefore \cos A = \frac{60}{64} = {\cdot}93750$$

Take $a = 21{\cdot}85$ and $B = 70^\circ$, $c = \frac{a}{\cos B} = \frac{21{\cdot}85}{{\cdot}34202} = 64$ feet nearly.

Take $c = 64$ and $A = 20^\circ$. Then $a = c \sin A = 64 \times {\cdot}34202 = 21{\cdot}88$ feet, and $b = c \cos A = 64 \times {\cdot}98969 = 60{\cdot}14$ feet.

I have preferred to take three figures as illustrating the approximation, but by minute calculation the results should be more accurate.

Trigonometrical Ratios of Two Angles.—It has been clearly established that the relations between the sine, cosine, tangent, &c., of the sum or difference of two or more angles, and the sines, cosines, &c., of the angles themselves, are based on the following fundamental propositions:—

$$\sin(A + B) = \sin A . \cos B + \cos A . \sin B.$$
$$\cos(A + B) = \cos A . \cos B - \sin A . \sin B.$$
$$\sin(A - B) = \sin A . \cos B - \cos A . \sin B.$$
$$\cos(A - B) = \cos A . \cos B + \sin A . \sin B.$$

In this case (Fig. 168) A and B are the angles. Sin (A + B) is a fraction, but sin A + sin B is the sum of two fractions, and care should be taken to avoid any misunderstanding.

Then let us take H O G = angle A and G O F = the angle B. Then H O F = angle (A + B). In the line O F which bounds the angle (A + B) take any point P, and let drop the perpendicular P Q on O G, and P S on O H. Draw the perpendicular Q R and Q T to the lines P S and O H.

Then

$$QPR = 90^\circ - RQP = RQO = HOG = A.$$

Now

$$\text{Sin}\,(A + B) = \sin HOF = \frac{PS}{OP} = \frac{SR + RP}{OP} = \frac{QT}{OP} + \frac{RP}{OP}$$
$$= \frac{QT}{OQ} \cdot \frac{OQ}{OP} + \frac{PR}{PQ} \cdot \frac{PQ}{OP}$$
$$= \sin HOG.\ \cos GOF + \cos RPQ.\ \sin GOF$$
$$= \sin A \cos B + \cos A.\ \sin B.$$

Again

$$\text{Cos.}\,(A + B) = \cos HOF = \frac{OS}{OP} = \frac{OT - ST}{OP} = \frac{OT}{OP} - \frac{RQ}{OP}$$
$$= \frac{OT}{OQ} \cdot \frac{OQ}{OP} - \frac{RQ}{QP} \cdot \frac{QP}{OP}$$
$$= \cos HOG.\ \cos GOP - \sin RPQ.\ \sin GOP$$
$$= \cos A.\ \cos B - \sin A.\ \sin B.$$

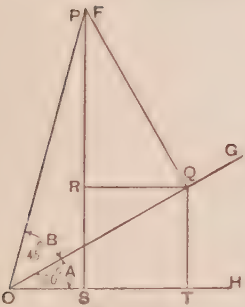


Fig. 168.

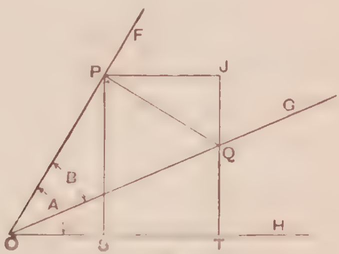


Fig. 169.

Now, to prove that

Sin $(A - B) = \sin A.\ \cos B - \cos A.\ \sin.\ B$, and $\cos (A - B) = \cos A.\ \cos B + \sin A.\ \sin B$, by reference to Fig. 169.

Let HOF = the angle A and GOF = the angle B. Consequently HOG is the angle $(A - B)$. Fig. 169.

In OG take any point Q, and from this let drop the perpendiculars QT, QP, perpendicularly to OH, OF. Then draw PJ at right angles to QT, and PS at right angles to OH. Then the angle $PQJ = 90° - JPQ = JPF = HOF$ = angle A.

Thus

$$\text{Sin}\,(A - B) = \sin HOG = \frac{TQ}{OQ} = \frac{TJ - QJ}{OQ} = \frac{SP}{OQ} - \frac{QJ}{OQ}$$
$$= \frac{SP \cdot OP}{OP \cdot OQ} - \frac{QJ \cdot PQ}{PQ \cdot OQ} = \frac{SP}{OP} \cdot \frac{OP}{OQ} - \frac{QJ}{PQ} \cdot \frac{PQ}{OQ}$$
$$= \sin HOF.\ \cos GOF - \cos JQP.\ \sin GOF$$
$$= \sin A.\ \cos B - \cos A.\ \sin B.$$

Similarly

$$\text{Cos}\ (A - B) = \cos HOG = \frac{OT}{OQ} = \frac{OS + ST}{OQ} = \frac{OS}{OQ} + \frac{PJ}{OQ}$$

$$= \frac{OS \cdot OP}{OP \cdot OQ} + \frac{PJ \cdot PQ}{PQ \cdot OQ} = \frac{OS}{OP} \cdot \frac{OP}{OQ} + \frac{PJ}{PQ} \cdot \frac{PQ}{OQ}$$

$$= \cos HOF.\ \cos GOF + \sin JQP.\ \sin GOF$$

$$= \cos A.\ \cos B + \sin A.\ \sin B.$$

To illustrate the foregoing formulæ we will find the value of sin 75°.

By the preceding

Sin. 75° = sin (45° + 30°) = sin 45°. cos 30° + cos 45°. sin 30°.

And we have seen (pages 121, 122) that

$$\sin 45° = \frac{1}{\sqrt{2}};\ \cos 45° = \frac{1}{\sqrt{2}};\ \sin 30° = \frac{1}{2};\ \cos 30° = \frac{\sqrt{3}}{2}$$

Therefore

Sin 75° = sin 45° cos 30° + cos 45°. sin 30°

$$= \frac{1}{\sqrt{2}} \cdot \frac{\sqrt{3}}{2} + \frac{1}{\sqrt{2}} \cdot \frac{1}{2}$$

$$= \frac{\sqrt{3} + 1}{2\sqrt{2}} = \frac{\sqrt{2}\,(\sqrt{3} + 1)}{4} =$$

$$\frac{1 \cdot 41421\ (1 \cdot 73205 + 1)}{4} = \frac{3 \cdot 8636924305}{4} = \cdot 96592.$$

Again

Cos 75° = cos 45°. cos 30° − sin 45°. sin 30°

$$= \frac{1}{\sqrt{2}} \cdot \frac{\sqrt{3}}{2} - \frac{1}{\sqrt{2}} \cdot \frac{1}{2}$$

$$= \frac{\sqrt{3} - 1}{2\sqrt{2}} = \cdot 25882.$$

From the foregoing remarks we have seen that :—

1st. The sine of the sum of two angles is equal to the sine of the first into the cosine of the second, together with the cosine of the first into the sine of the second.

2nd. The cosine of the sum of two angles is equal to the product of the cosines of the angles, less by the product of their sines.

3rd. The sine of the difference of two angles is equal to the sine of the first angle into the cosine of the second, less by the cosine of the first into the sine of the second.

4th. The cosine of the difference of the two angles is equal to the product of the cosines of the angles, together with the product of their sines.

Again

The tangent of the sum of two angles is equal to the sum of their tangents, divided by unity less the product of their tangents.

Take the angles A and B as before. Then

$$\text{Tan.}\ (A + B) = \frac{\tan A + \tan B}{1 - \tan A \,.\, \tan B.}$$

And in proof of this, if we use the foregoing formulæ, we have as follows:—

$$\text{Tan}\ (A + B) = \frac{\sin A.\ \cos B + \cos A.\ \sin B}{\cos A.\ \cos B - \sin A.\ \sin B.}$$

And dividing the numerator and denominator by cos A, cos B, we have

$$\text{Tan.}\ (A + B) = \frac{\dfrac{\sin A}{\cos A} + \dfrac{\sin B}{\cos B}}{1 - \dfrac{\sin A}{\cos A} \cdot \dfrac{\sin B}{\cos B}}$$

Therefore

$$\text{Tan}\ (A + B) = \frac{\tan A + \tan B}{1 - \tan A.\ \tan B.}$$

And similarly

$$\text{Tan}\ (A - B) = \frac{\tan A - \tan B}{1 + \tan A.\ \tan B.}$$

We have seen by the fundamental formulæ that

$$\begin{aligned}
\text{Sin}\ (A + B) &= \sin A.\ \cos B + \cos A.\ \sin B. \\
\text{Sin}\ (A - B) &= \sin A.\ \cos B - \cos A.\ \sin B. \\
\text{Cos}\ (A + B) &= \cos A.\ \cos B - \sin A.\ \sin B. \\
\text{Cos}\ (A - B) &= \cos A.\ \cos B + \sin A.\ \sin B.
\end{aligned}$$

And from these, by addition and subtraction, we get

Sine and Difference of Sines and Cosines.—

$$\begin{aligned}
\text{Sin}\ (A + B) + \sin\ (A - B) &= 2 \sin A.\ \cos B. \\
\text{Sin}\ (A + B) - \sin\ (A - B) &= 2 \cos A.\ \sin B. \\
\text{Cos}\ (A + B) + \cos\ (A - B) &= 2 \cos A.\ \cos B. \\
\text{Cos}\ (A - B) - \cos\ (A + B) &= 2 \sin A.\ \sin B
\end{aligned}$$

The sum of the sines of any two angles is to the difference of their sines in the same ratio as the tangent of half their sum is to the tangent of half their difference,

Or,

$$\sin A + \sin B : \sin A - \sin B :: \tan \tfrac{1}{2}(A + B) : \tan \tfrac{1}{2}(A - B).$$

For, from the preceding formulæ,

$$\frac{\sin A + \sin B}{\sin A - \sin B} = \frac{2 \sin \frac{1}{2}(A + B) \cos \frac{1}{2}(A - B)}{2 \sin \frac{1}{2}(A - B) \cos \frac{1}{2}(A + B)}$$

$$= \tan \tfrac{1}{2}(A + B) \cos \tfrac{1}{2}(A - B).$$

Or in the form of proportion,

$$\sin A + \sin B : \sin A - \sin B :: \tan \tfrac{1}{2}(A + B) : \tan \tfrac{1}{2}(A - B).$$

The Sine and Cosine of Twice an Angle, in Terms of the Sine and Cosine of the Angle.—We have seen that $\cos 2A = \cos^2 A - \sin^2 A$; and in the first equation, page 112, it was proved that $1 = \cos^2 A + \sin^2 A$;

$$\therefore\ 1 + \cos 2A = 2 \cos^2 A \quad \ldots\ldots \quad (a),$$
$$\text{and } 1 - \cos 2A = 2 \sin^2 A \quad \ldots\ldots \quad (b).$$

By transposition the following expressions for the cosine of twice the angle are obtained :—

$$\cos 2A = 1 - 2 \sin^2 A \quad \ldots\ldots \quad (c).$$
$$\cos 2A = 2 \cos^2 A - 1 \quad \ldots\ldots \quad (d).$$

The Sine and Cosine of an Angle in Terms of Half the Angle.—Replacing A for 2 A on the left, and $\frac{1}{2}$ A for A on the right-hand side of the equation $\sin 2A = 2 \sin A \cos A$, we get—

$$\sin A = 2 \sin \tfrac{1}{2}A . \cos \tfrac{1}{2}A \quad \ldots\ldots \quad (e)$$
$$\text{Again, } 1 + \cos A = 2 \cos^2 \tfrac{1}{2}A \quad \ldots\ldots \quad (f)$$
$$1 - \cos A = 2 \sin^2 \tfrac{1}{2}A \quad \ldots\ldots \quad (g)$$
$$\cos A = 2 \cos^2 \tfrac{1}{2}A - 1 \quad \ldots\ldots \quad (h)$$
$$\cos A = 1 - 2 \sin^2 \tfrac{1}{2}A \quad \ldots\ldots \quad (i)$$

Sine, Cosine, and Tangent of the Sum of Three Angles.—$\sin (A + B + C) = \sin (A + B) \cos C + \cos (A + B) \sin C$

$= (\sin A. \cos B + \cos A \cdot \sin B) \cos C + (\cos A \cdot \cos B - \sin A \cdot \sin B) \sin C = \sin A \cdot \cos B \cdot \cos C + \sin B \cdot \cos C \cdot \cos A + \sin C \cdot \cos A \cdot \cos B - \sin A; \sin B \cdot \sin C \; . \; . \; . \; . \; (k)$

And $\cos (A + B + C) = \cos (A + B) \cos C - \sin (A + B) \sin C = (\cos A \cdot \cos B - \sin A \cdot \sin B) \cos C - (\sin A \cdot \cos B + \cos A \cdot \sin B) \sin C = \cos A \cdot \cos B \cos C - \cos A \cdot \sin B \cdot \sin C - \cos B \cdot \sin C \cdot \sin A - \cos C \cdot \sin A \cdot \sin B \; . \; . \; . \; . \; (l)$

Dividing the expression for the sine by that for the cosine, and then dividing both numerator and denominator by $\cos A. \cos B, \cos C$, we get that for the tangent of the sum of three angles in the terms of the tangents of the angles themselves—

$$\text{Tan} (A + B + C)$$

$$= \frac{\tan A + \tan B + \tan C - \tan A \cdot \tan B \cdot \tan C}{1 - \tan A \cdot \tan B - \tan B \cdot \tan C - \tan C \cdot \tan A} \; . \; . \; . \; . \; (m)$$

And—

$$\text{Tan} (A + B) = \frac{\tan A + \tan B}{1 - \tan A \cdot \tan B} \; . \; . \; . \; . \; (n)$$

$$\text{Tan} (A - B) = \frac{\tan A - \tan B}{1 + \tan A \cdot \tan B} \; . \; . \; . \; . \; (o)$$

For proof of equation n, we have seen that—

$$\text{Tan} (A + B) = \frac{\sin (A + B)}{\cos (A + B)} = \frac{\sin A \cdot \cos B + \cos A \cdot \sin B}{\cos A \cdot \cos B - \sin A \cdot \sin B}$$

Then dividing the numerator and denominator of this expression by $\cos A. \cos B$. we obtain

$$\text{Tan} (A + B) = \frac{\dfrac{\sin A \cdot \cos B}{\cos A \cdot \cos B} + \dfrac{\cos A \cdot \sin B}{\cos A \cdot \cos B}}{\dfrac{\cos A \cdot \cos B}{\cos A \cdot \cos B} - \dfrac{\sin A \cdot \sin B}{\cos A \cdot \cos B}}$$

$$= \frac{\tan A + \tan B}{1 - \tan A \cdot \tan B} \; . \; . \; . \; . \; (p)$$

The Sine, Cosine, and Tangent of Three Times an Angle.— In the above equation, put $A = B = C$, then

$$\text{Sin } 3A = 3 \sin A - 4 \sin^3 A \; . \; . \; . \; . \; (q)$$
$$\text{Cos } 3A = 4 \cos^3 A - 3 \cos A \; . \; . \; . \; (r)$$
$$\text{Tan } 3A = \frac{3 \tan A - \tan^3 A}{1 - 3 \tan^2 A} \; . \; (s)$$

As another proof of the latter

$$\text{Tan } 3\text{A} = \tan(2\text{A} + \text{A}) = \frac{\tan 2\text{A} + \tan \text{A}}{1 - \tan 2\text{A}.\tan \text{A}}$$

$$= \frac{\dfrac{2\tan \text{A}}{1 - \tan^2\text{A}} + \tan \text{A}}{1 - \dfrac{2\tan \text{A}}{1 - \tan^2\text{A}}\tan \text{A}} = \frac{2\tan \text{A} + \tan \text{A} - \tan^3\text{A}}{1 - \tan^2\text{A} - 2\tan^2\text{A}}$$

$$= \frac{3\tan \text{A} - \tan^3\text{A}}{1 - 3\tan^2\text{A}}.$$

Oblique-angled Triangles.—I now pass on to the consideration of oblique-angled triangles, which, in the limited space at my command, I can discuss only in brief terms. I will commence by submitting the following propositions:—

A. Any two sides of a plane triangle are in the same ratio as the sines of the opposite angle.

B. In a plane triangle the sum of the sides is to their difference in the same ratio as the tangent of half the sum of the angles at the base of the triangle is to the tangent of half their difference.

C. In a plane triangle the base is to the sum of the sides in the same ratio as the cosine of half the sum of the base angles is to the cosine of half their difference; and the base is to the difference of the sides in the same ratio as the sine of half the sum of the base angles is to the sine of half their difference.

D. The square of a side of a plane triangle, which is opposite an acute or obtuse angle, is equal to the sum of the square of the sides which contain the angle, less by twice the rectangular under them, into the cosine of the angle.

The foregoing propositions form the basis of the consideration of the formulæ for the solution of oblique angles, and we will briefly consider them *seriatim*:—

Proposition A. Take the triangle A B C (Figs. 170 and 171), and

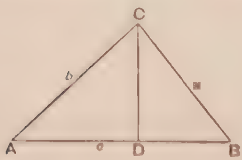


Fig. 170.

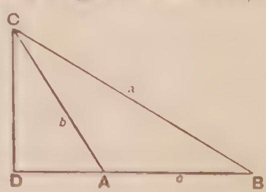


Fig. 171.

from C drop the perpendicular C D on to A B in Fig. 170 or A B produced in Fig 171. Then

$$\frac{a}{b} = \frac{\sin \text{A}}{\sin \text{B}}; \text{ for } \sin \text{A} = \frac{\text{C D}}{\text{A C}} \text{ and } \sin \text{B} = \frac{\text{C D}}{\text{C B}}$$

Therefore

$$\frac{\sin A}{\sin B} = \frac{\frac{CD}{AC}}{\frac{CD}{CB}} = \frac{CB}{AC} = \frac{a}{b}$$

Again

$$\frac{a}{c} = \frac{\sin A}{\sin C}; \ \frac{b}{c} = \frac{\sin B}{\sin C}.$$

It should be noted that if the angle A or B be a right angle, there is no necessity to drop the perpendicular C D. From this proposition we may state the ratio between the sides and the sines of opposite angles. Thus—

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}.$$

Proposition B. From the preceding we have—

$$\frac{a}{b} = \frac{\sin A}{\sin B}.$$

Then—

$$\frac{a+b}{a-b} = \frac{\sin A + \sin B}{\sin A - \sin B}.$$

Whence—

$$\frac{a+b}{a-b} = \frac{\tan \frac{1}{2}(A+B)}{\tan \frac{1}{2}(A-B)},$$

which may be treated thus—

Since $\qquad \frac{1}{2}(A+B) = \frac{1}{2}(180^\circ - C);$

Therefore

$$\tan \tfrac{1}{2}(A+B) = \tan(90^\circ - \tfrac{1}{2}C) = \cot \tfrac{1}{2}C;$$

$$\therefore \frac{a+b}{a-b} = \frac{\cot \frac{1}{2}C}{\tan \frac{1}{2}(A-B)} = \cot \tfrac{1}{2}(A-B)\cot \tfrac{1}{2}C.$$

Whence

$$\frac{a-b}{a+b} = \tan \tfrac{1}{2}(A-B)\tan \tfrac{1}{2}C$$

Proposition C.

$$A + B = 180^\circ - C, \therefore \sin(A + B) = \sin C.$$

$$\therefore \frac{a}{c} = \frac{\sin A}{\sin(A + B)}, \text{ and } \frac{b}{c} = \frac{\sin B}{\sin(A + B)}.$$

And by previous equations we get

$$\frac{a + b}{c} = \frac{\sin A + \sin B}{\sin(A + B)} = \frac{2 \sin \frac{1}{2}(A + B) \cos \frac{1}{2}(A - B)}{2 \sin \frac{1}{2}(A + B) \cos \frac{1}{2}(A + B)}$$

Consequently $$\frac{a + b}{c} = \frac{\cos \frac{1}{2}(A - B)}{\cos \frac{1}{2}(A + B)}.$$

And similarly by subtracting the second from the first equation instead of addition,

$$\frac{a - b}{c} = \frac{\sin \frac{1}{2}(A - B)}{\sin \frac{1}{2}(A + B)}.$$

Proposition D. In the case of an acute angle, Fig. 170,

$$BC^2 = AC^2 + AB^2 - 2\,AB.AD \text{ (Euclid. ii. 13).}$$

But $$\cos A = \frac{AD}{AC}, \therefore AD = AC \cos A,$$

and $$\therefore BC^2 = AC^2 + AB^2 - 2\,AB \cdot AC \cos A.$$

In the case of an obtuse angle, Fig. 171,

$$BC^2 = AC^2 + AB^2 + 2\,AB \cdot AD$$

But $$AD = AC \cdot \cos(180^\circ - A) = -AC \cos A,$$

and $$\therefore BC^2 = AC^2 + AB^2 - 2\,AB \cdot AC \cdot \cos A.$$

Therefore $$a^2 = b^2 + c^2 - 2\,b\,c \cos A$$

Similarly $$b^2 = c^2 + a^2 - 2\,c\,a \cdot \cos B,$$

and $$c^2 = a^2 + b^2 - {}^2a\,b \cos C.$$

Sines and Cosines of Angles in Terms of Sides.—From the foregoing we get by transposition :—

$$\text{Cos } A = \frac{b^2 + c^2 - a^2}{2\,b\,c},$$

$$\text{Cos } B = \frac{c^2 + a^2 - b^2}{2\,c\,a},$$

$$\text{Cos } C = \frac{a^2 + b^2 - c^2}{2\,a\,b}.$$

Now $$\sin^2 A = 1 - \cos^2 A$$

$$= (1 + \cos A)\ (1 - \cos A)$$

$$= \left(1 + \frac{b^2 + c^2 - a^2}{2\,b\,c}\right)\ \left(1 - \frac{b^2 + c^2 - a^2}{2\,b\,c}\right)$$

$$= \left(\frac{2\,b\,c + b^2 + c^2 - a^2}{2\,b\,c}\right)\ \left(\frac{2\,b\,c - b^2 - c^2 + a^2}{2\,b\,c}\right)$$

$$= \left(\frac{(b^2 + 2\,b\,c + c^2) - a^2}{2\,b\,c}\right)\ \left(\frac{a^2 - (b^2 - 2\,b\,c + c^2)}{2\,b\,c}\right)$$

$$= \left(\frac{(b + c)^2 - a^2}{2\,b\,c}\right)\ \left(\frac{a^2 - (b - c)^2}{2\,b\,c}\right)$$

$$= \frac{(a + b + c)\ (b + c - a)\ (a + b - c)\ (a + c - b)}{4\,b^2\,c^2}$$

Consequently, extracting the square root, we may obtain the sine of A.

If, however, we substitute s for $\frac{a + b + c}{2}$ (or as it is sometimes designated the *semiperimeter* of the triangle) so that $(a + b + c) = 2\,s$, and

$$\begin{aligned} 2\,(s - a) &= b + c - a, \\ 2\,(s - b) &= a + c - b, \\ 2\,(s - c) &= a + b - c; \end{aligned}$$

then by extracting the root we get

$$\sin A = \frac{2\,\sqrt{s\,(s - a)\,(s - b)\,(s - c)}}{b\,c},$$

$$\sin B = \frac{2\,\sqrt{s\,(s - a)\,(s - b)\,(s - c)}}{c\,a},$$

$$\sin C = \frac{2\,\sqrt{s\,(s - a)\,(s - b)\,(s - c)}}{a\,b}.$$

Sines and Cosines of Semi-angles.—We have seen that

$$\sin^2 \tfrac{1}{2}\,A = \tfrac{1}{2}\,(1 - \cos A) = \frac{2\,(s - b)\,2\,(s - c)}{4\,b\,c} = \frac{(s - b)\,(s - c)}{b\,c}$$

or extracting the square root we get

$$\sin \tfrac{1}{2}\,A = \sqrt{\frac{(s - b)\,(s - c)}{b\,c}}$$

and similarly

$$\operatorname{Sin} \tfrac{1}{2} \text{B} = \sqrt{\frac{(s-c)(s-a)}{c\,a}},$$

and

$$\operatorname{Sin} \tfrac{1}{2} \text{C} = \sqrt{\frac{(s-a)(s-b)}{a\,b}}.$$

Again

$$\operatorname{Cos} \tfrac{1}{2} \text{A} = \sqrt{\frac{s(s-a)}{b\,c}},$$

$$\operatorname{Cos} \tfrac{1}{2} \text{B} = \sqrt{\frac{s(s+b)}{c\,a}},$$

$$\operatorname{Cos} \tfrac{1}{2} \text{C} = \sqrt{\frac{s(s-c)}{a\,b}}.$$

Consequently, since $\tan \text{A} = \dfrac{\sin \text{A}}{\cos \text{A}}$

$$\therefore \qquad \operatorname{Tan} \tfrac{1}{2} \text{A} = \frac{\sin \frac{1}{2} \text{A}}{\cos \frac{1}{2}} = \sqrt{\frac{(s-b)(s-c)}{s(s-a)}},$$

and

$$\operatorname{Tan} \tfrac{1}{2} \text{B} = \sqrt{\frac{(s-c)(s-a)}{s(s-b)}},$$

and

$$\operatorname{Tan} \tfrac{1}{2} \text{C} = \sqrt{\frac{(s-a)(s-b)}{s(s-c)}}.$$

Logarithms.—It is necessary at this stage to say a few words regarding logarithms, or the ratio of numbers, without which it is impossible to consider the question of the solution of triangles. The principle is, that a fixed number called the base, raised to the proper power, may be made to represent any required number.

I must refer the student, who has yet to master the theory of logarithms, to the many suitable works upon the subject. In this present work space will only admit of an explanation of the use of tables of logarithms.

We propose to use the *common system* of logarithms, in which the base is 10.

Logarithms of numbers consist of two parts, viz. the *index or characteristic* and the *mantissa*. The characteristic represents a certain value, according to the number of figures in the number of which the logarithm is required. This value is always one *less* than that number, so that if there are seven integral figures, the characteristic would be represented on the left side of the decimal-point by 6, if six figures by 5, if five by 4, if four by 3, and so on. If, however, there are no whole numbers, then as the nature of the decimal fraction so the relative value of the characteristic, which now assumes a negative form, and is denoted by a *minus* sign being placed over the characteristic.

The *mantissa* is the decimal part of the logarithm, upon the right side of the point, and is to be found in the left-hand columns of mathematical tables opposite the number in the first column of which the logarithm is required. It is the same for any number of figures, provided they are of the same character. Thus the logarithm of 45858 will appear as 4·6614151, whilst 4585·8, consisting of only four whole numbers, although representing the five same figures, reads thus, 3·6614151; and for the same reason 458·58 = 2·6614151, and so on, being regulated by the number of integral figures. But if there are no whole numbers, so that ·45858 appears as a fraction, then the negative characteristic is adopted, its value increasing in the same way that it formerly decreased.

The following is an illustration of the manner in which the characteristic will appear:—

Number.	Logarithm.
45858·	4·6614151
4585·8	3·6614151
458·58	2·6614151
45·858	1·6614151
4·5858	0·6614151
·45858	$\bar{1}$·6614151
·045858	$\bar{2}$·6614151
·0045858	$\bar{3}$·6614151
.00045858	$\bar{4}$·6614151

It will be therefore understood that the mantissa may be found in the tables, but the characteristic has to be determined by the number of figures, according to circumstances.

Here let me explain that most tables of logarithms have numbers only to 9999, and by reference thereto they appear thus:—

No.	0	1	2	3	4	5	6	7	8	9	D
7695	8862086	2143	2199	2256	2312	2368	2425	2481	2538	2594	57

so that in reality we only get the logarithm of the first four of the five figures, viz. L for 7695 = ·8862086; but we want the log. of 76952, to get which we must look in one of the right-hand columns marked 2, and for the last four decimals, viz. 2086, substitute the four in column 2, viz. 2199, so that our log. of 76952 is 4·8862199; equally if we wanted the logarithm of 76959 we should in the ninth column substitute 2594 for the four last decimals opposite 7695, so that the logarithm of 76959 = 4·8862594. Now in the last column, headed D, it will be noticed one solitary set of

figures, viz. 57; this means that it is the difference between the logarithm of the number and the following unit.

Thus Log. 7695 = ·8862086. Add 57.

$$\begin{array}{ll} \text{Log. } 7695 = & \cdot 8862086. \quad \text{Add 57.} \\ & \underline{\qquad\quad 57} \\ \text{Then Log. } 76951 = & \cdot 8862143. \quad \text{Add 57.} \\ & \underline{\qquad\quad 57} \\ \text{Log. } 76952 = & \cdot 8862200.^{*} \quad \text{Add 57.} \\ & \underline{\qquad\quad 57} \\ & \cdot 8862257, \text{ and so on.} \end{array}$$

It being impossible in a single chapter to deal with logarithms exhaustively, I must content myself with a brief introduction to the subject, referring the student to other works for any more elaborate consideration.

Multiplication by Logarithms.—*Rule.*—Find the logarithms of the numbers to be multiplied, and add them together. The sum will be the logarithm of the product. Thus—

Multiply 621 by 412.

$$\begin{array}{rl} \text{Log. } 621 = & 2{\cdot}7930916 \\ \text{Log. } 412 = & \underline{2{\cdot}6148972} \\ \text{Log. of product} = & 5{\cdot}4079888 = \text{Log. } 255{\cdot}852 \\ \therefore \text{product} = & 255{\cdot}852 \end{array}$$

Division by Logarithms.—*Rule.*—Subtract the logarithm of the divisor from that of the dividend, and the remainder will be the logarithm of the quotient.

Example.

Divide 8882·2 by 4·7.

$$\begin{array}{rl} \text{Log. } 8882{\cdot}2 = & 3{\cdot}5890779 \\ 4{\cdot}7 = & \underline{{\cdot}6720979} \\ \text{Log. of quotient} = & 2{\cdot}9169800 = \text{Log. } 826 \\ \therefore \text{quotient} = & 826. \end{array}$$

Proportion by Logarithms.—*Rule.*—The logarithms of the two middle terms are to be added together, and from their sum the logarithm of the first must be subtracted, and the remainder will be the logarithm of the quantity required;

Or, instead of subtracting the logarithm of the first term from the sum of the second and third add its *arithmetical complement*, and from this sum deduct 10 from the characteristic.

* Owing to this table being only worked out to seven places of decimals, there is an inappreciable discrepancy, as by the table the log. of 76952 is ·8862199.

Note.—The *arithmetical complement* of a logarithm may be found by deducting it from 10. Thus, if the logarithm of 685 = 2·9469433, its arith. compl. = 10·0000000 − 2·9469433 = 7·0530567.

The following example will serve to illustrate the two methods of performing proportion:—

If the wages of a servant be £25 per annum, what amount should he receive for 87 days' service?

Then—

As 365 : 87 : : £25 : ?

By Logarithms.	By Arithmetical Computation.
As L 87 = 1·9395193	1·9395193
L £25 = 1·3979400	1·3979400
L 365 = 2·5622929	7·4377071 *
·7751664	·7751664

Answer, £5 19s. 2½d.

Involution by Logarithms.—*Rule.*—Multiply the logarithm of the given number by the exponent of the power, and the product will be the logarithm of the required power.

Find the square of 75.

$$\text{Log. } 75 = 1\cdot8750613$$
$$2$$
$$\therefore \text{ Log. Product} = 3\cdot7501226 = \text{Log. } 5{,}625$$
$$\therefore\ 75^2 = 5625.$$

Similarly find the cube of 62.

$$\text{Log. } 62 = 1\cdot7923917$$
$$3$$
$$\therefore \text{ Log. Product} = 5\cdot3771751 = \text{Log. } 238{,}328$$
$$\therefore\ 62^3 = 238{,}328.$$

Again, find the fifth power of 18.

$$\text{Log. } 18 = 1\cdot2552725$$
$$5$$
$$\therefore \text{ Log. Product} = 6\cdot2763625 = \text{Log. } 1{,}889{,}568$$
$$\therefore\ 18^5 = 1{,}889{,}568.$$

Evolution by Logarithms.—*Rule.*—Divide the logarithm of the given number by the exponent of the root, and the quotient will be the logarithm of the required root.

* 10·0000000 − 2·5622929 = 7·4377071.

Examples.

Find the square root of 256.

$$\begin{aligned} \text{Log. } \sqrt{256} = \tfrac{1}{2} \text{ Log. } 256 &= \tfrac{1}{2} \times 2{\cdot}4082400 \\ &= 1{\cdot}2041200 \\ &= \text{Log. } 16. \end{aligned}$$

$$\text{And} \therefore \sqrt{256} = 16.$$

Again, find cube root of 256.

$$\begin{aligned} \text{Log. } \sqrt[3]{256} &= \tfrac{1}{3} \times 2{\cdot}4082400 \\ &= {\cdot}8027466 \\ &= \text{Log. } 6{\cdot}3496 \end{aligned}$$

$$\therefore \sqrt[3]{256} = 6{\cdot}3496$$

And so evolution to any extent may be performed, simply by dividing the logarithm of the given number by the exponent of the root.

Natural and Logarithmic Sines, Cosines, &c.—We have seen that the ratio of the perpendicular to the hypotenuse, of that of the base to the hypotenuse, &c., give the natural sine, cosine, &c. As in the case of the angle of 45 deg., we found that

$$\begin{aligned} \text{Sin } 45^\circ &= 0{\cdot}70711 \\ \text{Cos } 45^\circ &= 0{\cdot}70711 \\ \text{Tan } 45^\circ &= 1{\cdot}00000 \\ \text{Cotan } 45^\circ &= 1{\cdot}00000 \\ \text{Sec } 45^\circ &= 1{\cdot}41421 \\ \text{Cosec } 45^\circ &= 1{\cdot}41421 \end{aligned}$$

And similarly

$$\begin{aligned} \text{Sin } 60^\circ &= 0{\cdot}86602 \\ \text{Cos } 60^\circ &= 0{\cdot}50000 \\ \text{Tan } 60^\circ &= 1{\cdot}73210 \\ \text{Cot } 60^\circ &= 0{\cdot}57735 \\ \text{Sec } 60^\circ &= 2{\cdot}00000 \\ \text{Cosec } 60^\circ &= 1{\cdot}15470 \text{ and so on.} \end{aligned}$$

We have further seen that these values express the lengths of the sines and cosines of arcs of a circle whose radius = 1; so also with logarithmic sines, cosines, &c., taking the radius as 10, we are able to simplify our calculations in the solution of triangles.

Thus the natural sine of 37° = 0·60182, whilst the logarithmic sine of 37° = 9·77946.

The natural sines, cosines, tangents, &c. may be found from the logarithmic sines, cosines, tangents, &c., by subtracting 10 from the indices of the latter, and then the number corresponding to this logarithm is the natural sine, cosine, tangent, &c., required.

Example.—The logarithmic sine of 37 deg. = 9·77946, from which it is required to find the natural sine.

Log. sin. 37°	= 9·77946
Subtract	10·
Log. nat. sin.	= $\bar{1}$·77946
Hence natural sin. =	·60182

It may be well here to state some of the peculiar properties of the lines in and about a circle as follows :—

1. The square of the diameter is equal to the sum of the squares of the chord of an arc, and of the chord of its supplement to a semicircle.

2. The square of the radius is equal to the sum of the squares of the sine and cosine.

3. The sum of the cosine and versed sine is equal to the radius.

4. Radius is to the sine as twice the cosine is to the sine of twice the arc, or as the secant is to the tangent.

5. As the cosine is to the sine, so is the radius to the tangent.

6. Radius is the mean proportional between the tangent and the co tangent, and also between secant and cosine.

Arithmetical Computation.—The terms of proportion must be stated according to rule, which terms consist partly of the numbers which express the given lengths of sides, and partly of the sines, &c., of the given angles, in which case the logarithms of the second and third terms are to be added together, and from their sum the first must be subtracted; or else, when the radius is not concerned in the analogy, by taking the arithmetical complement of the first term, and adding it to the logarithms of the second and third terms, and subtracting 10, the natural number of which this aggregate is the logarithm is the fourth term of the proportion.

Trigonometry has four cases, viz. :—

1. When two sides and the angle opposite one of them is given.
2. When two sides and their included angle are given.
3. When three sides are given.
4. When two angles and a side are given.

Example in Case I.

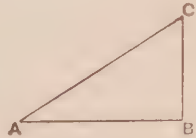


Fig. 172

Given triangle (Fig. 172) A B C.

The side A B = 500 links
„ B C = 288·67 „
Angle A = 30°

Rule I. :—

As one side : the sine of the opposite angle :: either of the other sides : the sine of its opposite angle

Then, to find the angle C—

	Log.
As the side B C = 288·67 links A R* . .	7·5395906
Is to the sine of its opposite angle A 30°	9·6989700
So is the side A B = 500 links . . .	2·6989700
To sine of opposite angle C = 60° . .	9·9375306

To find the side A C—

As sine of angle A = 30°	9·6989700
Is to B C = 288·67 links	2·4604094
So is sin B = 90°	10·0000000
	12·4604094
	9·6989700
To A C = 577·35	2·7614394

N.B.—C has been determined from its sine.

Now, Sin A = sin (180° — A), hence C may have one of two values.

In Fig. 172A the triangles A B C, A B C′ have the lengths of the sides A B, B C (or A B, B C′) given, and the angle A given, and we at once see that two triangles satisfy these quantities.

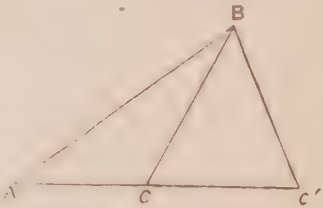


Fig. 172A.

This is called the *ambiguous case.*

Solution of same Triangle by Natural Sines, &c.—To find the side B C—

B C = A C cos C = 577·36 × ·5 = 288·67 links.
or, B C = A B tan A = 500·00 × ·57735 = 288·67 ,,

To find the side A B—

A B = B C sec C = 288·67 × 2 = 577·34 links.

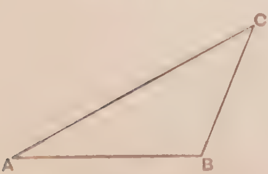


Fig. 173.

Oblique-angled Triangle.

Example.

Given triangle (Fig. 173) A B C.
Base A B = 610 links,
Angle B = 115°
Angle C = 42° 30

* A.R. is an abbreviation of *arithmetical complement*, which is the difference between the logarithm of a number and 10. Thus log. 288·67 = 2·4604094, then 10 – 2·4064094 = A.R. = 7·5395906.

Then, to find the side A C—

As the sine of the angle B : A C : : sine of angle C : the side A B.

Thus

As sin 42° 30′ arith. com.	0·170317
: the side A B 610	2·785329
: : sin of suppl. of angle B = 65°	9·957275
: A C = 818·32 links.	2·912921

To find the side B C.

As sine of angle 42° 30′ arith. comp.	0·170317
: side A B = 610	2·785329
: : sin of angle A = 22° 30′	9·582839
: B C = 345·53 links	2·538485

RULE II.—As the sum of the two given sides is to the difference of those sides, so is the tangent of half the sum of their opposite angles to the tangent of half their difference.

This half difference, added to the half sum, will give the greater angle, and taken from the half sum will give the less angle.

Example.

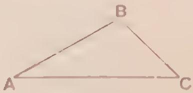


Fig. 174.

Given (Fig. 174) A B = 1636 links.
B C = 1272
Angle B = 97° 30′

Required the angles A and C and the side A C.

As the sum of A B + B C = 2908 co-arith.	6·536406
: their differences = 364	2·561101
: : tan ½ the sum 41° 15′	9·942988
: tan ½ difference 6° 16′	9·040495
Their sum = 47° 31′ = angle C	
Their difference = 34° 59′ = ,, A	

Then for the side A C.

As sin angle A = 34° 59′	0·241589
: side B C = 1272	3·104487
: : sin angle B = 97° 30 suppl.	9·996269
: A C = 2199·6	3·342345

* The co-arith. is obtained by deducting the logarithm of the sum of the two sides from 10.

thus 10·0000000
log. 2908 = 3·4635944

6·5364056

Take the triangle (Fig. 175) with $b = 530$ links, $a = 923{\cdot}6$ links, and the angle $c = 29° 25'$ Required the angles A and C.

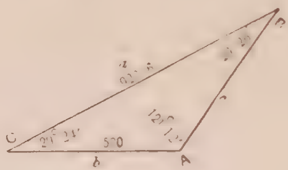


Fig. 175.

Now

530 + 923·6 = 1453·6	
and	10·0000000
Log. 1453·6	= 3·1624449
Co-arith. 1453·6	= 6·8375551
As 1453·6	6·8375551
: 923·6 — 530 = 393·6	2·5950551
: : tan of half sum.	
angle $= \dfrac{180° - 29° 25'}{2} = 75° 18'$	= 10·5811271
Tan of half diff. = 45° 54′	= 10·0137373

Therefore

$$75° 18' + 45°{\cdot}54' = \text{angle A} = 121° 12'$$
$$75° 18' - 45°{\cdot}54' = \quad ,, \quad c = \ \ 29° 24'$$

Rule III.—From the greatest angle let fall a perpendicular to the base or opposite side, dividing it into two segments, and the whole triangle into two right-angled triangles. Then

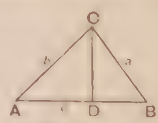


Fig. 176.

As the whole base : the sum of the other two sides : : the difference of those sides : the difference of the segment of the base.

Then half this difference of segment added to half the base will give the greater segment; and subtracted from half the base will leave the less segment.

Given (Fig. 176) A B = 2200 links.
,, A C = 1636 ,,
,, B C = 1272 ,,

Required the segments A D and D B and the angles.

Example.

As 2200 : 2908 :: 364 : 481 diff. of segments
Half diff. of segs. 240·5

adding to and subtracting from ½ base 1100
1340·5 = A D
859·5 = D B

For the Angle A.

As A C = 1636	3·213783
: radius	10·000000
:: A D = 1340·5	3·127105
	13·127105
: cos angle A = 35°	9·913322

Therefore angle A = 35°

For the Angle B.

As B C = 1272	3·104487
: radius	10·000000
:: D B = 860 (practically)	2·934498
	12·934498
: cos angle B = 47° 27′	9·830011

Therefore angle B = 47° 27′.

Consequently the angle C is as follows,

$$180° \, 00' - 35° \, 00' - 47° \, 27' = 97° \, 33'$$

Thus far I have demonstrated the solution of triangles by means of logarithms, and in conclusion I will give a few illustrations of how it may be done by natural sines, &c.

Take the triangle (Fig. 177) whose sides shall be as follows :—

A B = 747·7 links.
B C = 495·45 „
A C = 560·00 „

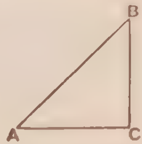


Fig. 177.

First to find the angles A and B.

$$\text{Now } \sin A = \frac{BC}{AB} = \frac{495·45}{747·70} = ·6626200$$

and opposite this in a table of natural sines will be found the angle 41° 30′ = angle A.

Similarly

$$\cos A = \frac{AC}{AB} = \frac{560\cdot00}{747\cdot70} = \cdot7489557$$

$$\text{But } \sin B = \frac{AC}{AB} \therefore \sin B = \cdot7489537 = \sin 48^\circ 30$$

the angle $B = 48° 30'$.

Then $180° 00' = 90° (C) + 41° 30' (A) + 48° 30' (B)$. And the side BC, AC, and AB may be found.

Inaccessible Distances.—It may be well to refer briefly to one or two problems in connection with inaccessible distances.

In case A (Fig. 178), we have the distances AB and the angle

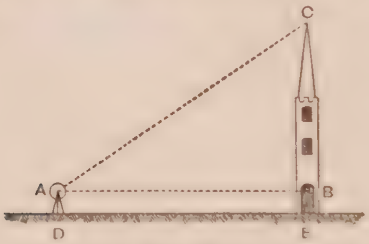


Fig. 178.

CAB given, and it is required to ascertain the height of the church steeple.

Then

$$CB = \tan. CAB \times AB$$

Case B (Fig. 179). Being impossible to measure from A to the church in consequence of a river intervening, it is necessary to

Fig. 179.

measure the line AB as long as possible, and at A and B to observe the angles CAF, CBF.

Then
$$\text{C F} = \frac{\text{A B}}{\text{cotan C A F} - \text{cotan C B F}}$$

Note.—In both cases, A and B, the height of the instrument from the ground A D or E B must respectively be added C B or C F.

Case C (Fig. 180). Suppose it be necessary to ascertain the length between two trees C D, but it is impossible to approach them by

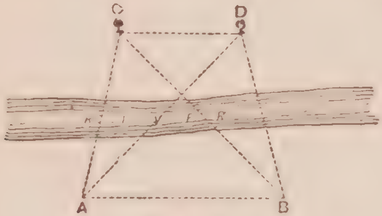


Fig. 180.

reason of the river. Having measured the base line A B very accurately, the angles C A B, C B A, D B A, and D A B must be observed; from which, by preceding problems, the sides C A, D B, C B, and D A must be calculated (see Oblique Triangle, page 142), together with the angles A C D, B D C, C D A, and D A C. With these, as has been shown, the length C D may be calculated.

CHAPTER V.

CHAIN SURVEYING.

Surveying with Chain only.—I have in the previous chapters elected to treat all the preliminary questions together, leaving the present exclusively for the consideration of chain-surveying of estates, &c., and the method of keeping the field-book, with such other matters as may appear necessary.

Field Book.—First I will deal with the field-book, because this is a very essential element in surveying. I may here say that the manner in which the field-book is kept is in the highest degree important, bearing as it does upon the accuracy with which the survey is made and plotted. It is quite a mistaken theory (commonly held by old-fashioned surveyors) that the field-book should be so kept as to be only understood by them. Those days have gone by, and the modern surveyor must be so qualified that his work is not only as clean and simple as possible, but is capable of the most searching scrutiny.

Ordnance Field Book.—The Ordnance surveyors are obliged to keep their field-books in ink, and so particular have they to be, that when the survey is completed the books are sent in to Southampton, and possibly are never seen again by the surveyor, for the work is plotted by special draughtsmen, who may never have seen the ground they have to plot; so that unless the book has been kept clean and accurate it would be impossible to plot the survey.

Necessity for Reconnoitre.—I have strongly recommended a reconnaissance previous to commencing a survey, for the purpose of determining the base and other lines, for establishing stations, and to make a sketch of the chief boundaries and features of the property. This latter is very important, not only to enable you to lay down the various lines, with their relative directions and positions, but in plotting will be found to be of the greatest assistance.

Survey Lines to be numbered consecutively.—The lines should be numbered consecutively from 1 upwards; and it is a great help to the surveyor if he represents his principal stations by

letters, as A, B, &c., for one cannot have too much detail in one's field-book, bearing forcibly in mind the fact that others than yourself may have to plot the work.

Conventional Signs.—It may be well at this point to refer to conventional signs which are usually adopted by surveyors to indicate special features :—

1. Ditch and hedge are shown by a straight line, which line

represents the edge of the ditch ; the hedge being delineated by a **T**, showing on which side it belongs.

2. Where a change of position of ditch and hedge occurs, it should be carefully noted as in the sketch, which shows that at a certain point the ditch passes to the other side of the hedge, so that on the left the hedge belongs to A and on the right to B.

3. When a hedge alone separates two properties and on neither side is there a ditch, it is called a "foot-set" fence, and is shown in the third illustration above.

4. In most cases it is desirable to show gates, and they may be delineated in either of the ways indicated.

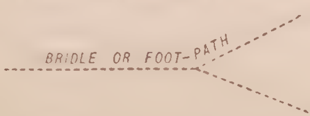
Gates thus :—

5. Post-and-rail fencing is shown thus :—

6. Close-paling thus :—

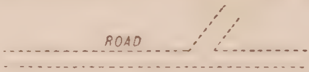
7. Walls by a double line.

8. Footpaths are shown by a single dotted line.

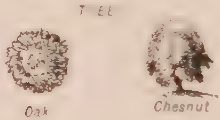


9. Cart-track or bridle-path by a double dotted line ; but in

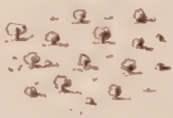
measuring upon the ground it is usual only to take the centre of the track, and allow twelve to fifteen links for the width.



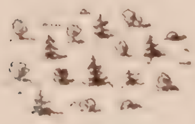
10. Trees are shown thus, and are described :—



11. Orchards are sketched thus :—



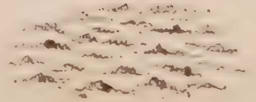
12. Woods.



13. Brushwood.

14. Marshy ground.

15. Heath or gorse.



16. Railways, or preferably by a strong blue line.

17. Railway embankment.

18. Railway cutting.

19. Broken ground or cliff.

20. Parish boundaries.

21. County boundaries.

22. Surveying stations.

23. Direction of line.

Field Book.—The usual kind of field-book is 8 inches long by 4½ inches wide, opening lengthwise, and having a central column

about $\frac{3}{4}$ inch wide for the longitudinal measurement, whilst the right and left columns are for marking the offsets, sketching in the fences, buildings, &c., and any memoranda that may be necessary, as in the following example:—

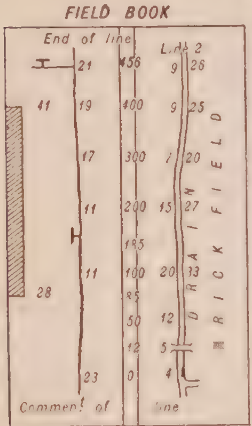


Fig. 181.

In Fig. 181 I have given but a very simple illustration of the use of such a field-book, and so long as all is plain sailing there may be little or no objection to this system; but in complicated work, where we have fences crossing our lines in all directions, and to take note of a large amount of detail, neither the size nor arrangement of the book can be recommended. For instance, supposing we have a fence crossing our chain-line obliquely, it would have to be entered in the book as in Fig. 182; or if a fence crosses our chain-line at right angles, but at the point of intersection another fence joins in an oblique direction, it would have to appear as in Fig. 183, the word "at" written against the sketch distinguishing that at 316 the oblique fence C joins A B at the point where it is intersected by the chain. Again, if our chain-line runs at a point on the edge of the ditch, so that in plotting at such a point the fence will impinge on the survey-line, it will

Fig. 182.

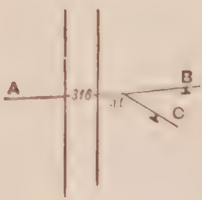


Fig. 183.

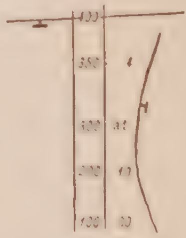


Fig. 184.

have to be shown in the field-book as in Fig. 184, the word "at" at 300 signifying that this is the point of impingement. Then as to noting the stations, I maintain that the double column is anything but convenient; and to illustrate my argument I have given (Fig. 185) a portion of a field-book the system of which is advocated by one of the best authorities on modern surveying, in which it will be seen that stations occur at 1025 for line No. 3 to the left; at 1425 for No. 9; 1740 and 1875 for lines Nos. 5 and 10; whilst at 2185

we have a station for the intersection of lines 13 and 14, and 3325 a station for No. 21; all being on the left side of the chain-line; the point of the station being delineated by a small circle outside the column against the chainage, with a dotted line to represent the direction of the line diverging from this station, whilst a circle enclosing a number indicates the line to which it refers. Can anything more troublesome be conceived—this extraneous sketching on the book to represent so little? so that to indicate that at 2185 there is a station whence two lines diverge involves three circles, two dotted lines, and two sets of figures, as in Fig. 186. I have taken the liberty of drawing a horizontal line above and below the stations in the central column,

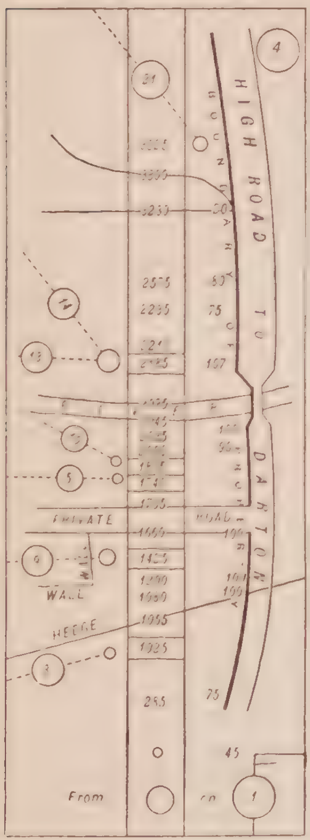


Fig. 185.

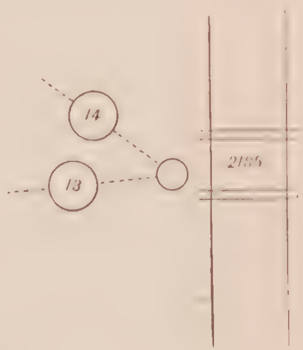


Fig. 186.

which is the custom of many surveyors, and it is sometimes done as in Fig. 185.

Best Size of Field Book.—In the first place, I maintain that the field-book is too small. I prefer a quarto size (opening lengthwise), which gives plenty of room for sketching in detail any features that may require to be taken, and for remarks, either as to the name of the field, &c., the description as to whether it is arable or pasture (distinguished by *ara.* or *pas.*), the county

and parish or township, the occupiers, and the proprietors of the adjoining lands, &c.

Single Line preferable to Double Column.—Instead of the central column, *I recommend a single line upon which the longitudinal measurements may be marked.* This line represents in the book what the chain does in the field, and any crossing or intersection of a fence can be accurately shown in its proper position and direction, and a station may be represented with greater facility by drawing a circle or oval round the distance.

To illustrate my meaning, I reproduce in Plate 2 (p. 156) a field-book adapted to the system I advocate, which is at once simple and intelligible, and one to which one soon gets accustomed. I have found it the most useful in my own practice; and in preparing a large number of pupils I have had ample evidence of the great facilities it affords.

Chain Survey of part of Wimbledon Park.—I give here also an example of a complete survey in Wimbledon Park recently executed by one of my pupils (see Plate 1). This is a survey of somewhat undulating ground, the rise from B to G being about 90 feet. Commencing at A at the north-eastern end of the property for line 1, it was found impossible to restrict the offsets to fifty links, as the point B was an important station; consequently we had offsets of ninety-nine links, which, as a rule, is too much; but as this survey was for a special purpose, connected with the higher ground, the absolute accuracy of this particular fence, to the left of the line 1, was not a matter of great moment, especially as in the subsequent operations of traversing the road this fence was carefully adjusted. On reaching B (at the end of line 1), we ran the line No. 2 to C; thence a third line to D, and back to line A by line 4. This trapesium was tied by the base-line B D and a check-line from *g* to A; an additional check-line E′ G completely secures the accuracy of this figure. The south-western corner of the property had to be taken by a triangle B E E′, tied by E *e*; whilst a further small triangle was necessary, b^1 b^2 E, tied by b^2, b^3. Line No. 6 from E to F, passing through B C at E′ and C D at G, was a survey line to take up the post-and-rail of the fencing of the road to Wimbledon Park. A small triangle is formed by line 6 from G to F, as much to keep up the curve of the fence on the western side as to accurately fix the position of the line E F. The north-western indent was taken up by means of a triangle H J D on the line C D, with a check-line H *h*.

Few Lines as possible.—Thus it will be seen that the whole of this figure has been accurately surveyed by means of as few lines as possible, and the accompanying field-book (Plate 2, p. 156), which is given in detail, will enable the student to plot this work

* In the field-book (Plate 2) the lines 8 and 9 are given on the page representing line 3.—G. W. U.

PART OF WIMBLEDON PARK.

Scale, 40 Chains to an Inch

Crosby Lockwood & Son, 7, Stationers Hall Court, London

for himself. Referring to line 1, it will be seen that the first point of importance at 550 is the gate, the position of which should be fixed by a small triangle upon the chain-line formed by 60 and 67 links at 600; the width of the gate in links between the posts to be noted in the field-book next. At 700 is a point on the chain-line which it is necessary to measure from to the corner where the small stack fence cuts the main fence. Similarly, each of the other corners should be fixed upon the chain-line by means of triangles as shown; and finally the small pond near the end of line 1 should be so treated. It should be noted that any defined point, such as an indentation in a fence, the position of a gate-post, the intersection of one fence with another, should be accurately fixed upon the survey-line by means of a triangle, and certainly on no account should such an important point be trusted to a simple offset.

Tape not to be used for Offsets.—In Chapter I. I have expressed a decided opinion against the use of a tape for taking offsets, and I shall here emphasise that opinion by remarking that the accuracy of a survey, however simple or elaborate, will best be assured by arranging the survey-lines so that the offsets shall be as short as possible.

Chain-men should be instructed as to their Duties.—In commencing a survey it is necessary that the surveyor should satisfy himself that his chain-men are thoroughly conversant with their duties, and that his chain has been properly tested.

Enter every Ten Chains in Field Book.—At the completion of every ten chains, the surveyor should enter that number in his field-book, seeing that the leader receives from the follower ten arrows, and, placing his foot against the end of the tenth chain, take care that the eleventh arrow is duly put in position.

Boning out Lines with Laths recommended.—It is a considerable saving of time if each line is well boned-out by means of laths, before referred to, especially where the ground is of an undulating character, as they are of great value in guiding both the leader and follower to keep well in line. At any point where it is deemed necessary to make a station, either a peg or a lath with a paper duly figured, or some distinguishing mark, should be left on the chain-line for future reference.

Best Form of Stations.—It is quite a mistake to imagine that by kicking a hole or cutting a mark in the turf the work will be facilitated, as often the time lost in trying to find this point subsequently is a matter of serious moment. If the survey is of an extensive character, occupying some considerable time, all stations and minor stations should be marked by pegs, each of which

should have a distinguishing letter or number, as shown by Fig. 7 in Chapter II.

Begin at the End of Book and work upwards.—Referring to the field-book in connection with Plate 1, I should explain that it is necessary to begin on the last page of the book, working upwards, using one side of the paper only; so that, as in the case of line 1, it would be observed, on reaching the end of the first page at 1100, it was necessary to carry line 1 over on to another page, as it terminates at 1604; on reaching which it is desirable to draw two dashes across the book to represent that you have finished that line, taking care to write at the beginning, "Commencement of line 1," and at the finish, "End of line 1."

Let each Line have a separate Page.—On no account attempt to commence another line on the same page, as paper is cheap enough to obviate such a necessity. It will be seen that all the offsets are on the left-hand side. Line 2 on the third page should be designated "Commencement of line 2," "End of line 1, right." At 489 is a station for a check-line to the end of line 5, and again at 735 there is another in connection with line 5. 739, 834, and 927, in line 2, intersect the post-and-rail fence which forms the boundary of the road, and between 834 and 927 there are points where it will be found necessary to take offsets to the right of the line to pick up the curvature of the aforesaid fence, whilst the final station of line 2 is at its termination 929. Here again it is necessary to draw two dashes across the book to show the completion of this line, and I would here say that I find it most convenient to indicate all stations by an oval enclosing the figures, thus 929, and, by means of one or more lines as the case may require, indicating the direction and nature of other lines connected with that station. Line 3, which commences at the end of line 2, crosses the road to Wimbledon Park and intersects line 5 at 151; a small line from the commencement of line 3 to the end of line 6 forms a triangle as much to check the position of these lines as to take up the curved fence on the left-hand side. Line 3 crosses the post-and-rail fence running alongside line 5, and thence, at the various points indicated, there are offsets on the right to the post-and-rail fence, and on the left to the boundary wall; at 573 there is a station for a tie-line to the commencement of line 1. At 870 and 900 are points whence a small triangle is formed to take up the corner of the boundary wall, whilst at 874·5 is a station for line 9 for the triangle necessary to take up the indentation at the north-west portion of the survey. The end of line 3 being the other point of the triangle on this line at 1296·5, for line 8, from which point also the base-line to the end of line 1 is commenced. Following this, upon another page, is a detailed sketch

(Plate 2) of the triangle before referred to, which needs no explanation. Line 4, beginning at the commencement of line 1 (runs to the end of line 3, as will be shown hereafter), and crosses the edge of a pond on the right-hand side, the boundaries of which have been fixed by the points where it crossed, and also offsets; and, further on the right-hand side, as are necessary, the post-and-rail fence was taken up by offsets, and on reaching the end of this line the junction of the two fences was determined by a diagonal offset from the station. From this point the base-line to the end of line 1 was carefully measured over very undulating ground. The reason for taking this step will now be seen, as from the end of line 1 we were able to survey the two triangles on the left-hand side of line 2 on lines 5, 6, and 7.

As I shall refer to this survey again under the head of "Theodolite Surveying and Traversing," I now content myself with recommending the student to plot this survey to a scale of 2 chains to an inch, which will afford him excellent practice both in plotting and the *modus operandi* with the chain only.

Mark Intersection of Lines by small Circles.—In plotting a survey, at all points of intersection of lines and stations, it is desirable to draw a very small circle round the point of intersection, and, after the principal lines have been carefully plotted, the exact length being determined by a puncture with a very fine needle before any detail is plotted, it is absolutely necessary that these lines be finally drawn in with lake or carmine, and on no account should a survey be plotted from pencil lines.

Best Form of Base Lines.—In the early part of this book I have expressed an opinion that a survey is best accomplished by treating its two main base-lines as intersecting the estate surveyed in the form of the letter X, and I cannot impress too strongly upon the student the desirability of doing this wherever practicable. As these lines should form the basis of a complete network of triangulation, it need hardly be said that where possible it is always desirable that the figures should be in the form of triangles.

Plate 3 (p. 158) is an illustration of a part chain and a part theodolite survey, the result of a course of lectures I delivered at Cardiff; and, having been first surveyed with the chain only, is applicable to the present consideration.

Line 1 commences at an acute angle of a fence A and runs to B. A station is left at b, for the purpose of tying in other lines. Line 2 from B to C is tied to line 1 by the line marked A'''. Line 3 from C to D is the longest line of the survey, and has upon it stations at d, d', and d''', and B'. From the stations d and d''', a triangle d, d'', d''' is set out for the purpose of taking up an indented fence on the eastern side of line 3, which triangle is tied

by the line d' d''. Line 4 from B′ is really a tie-line to complete the construction of the chain survey proper, and the lines 3 and 1 are tied in by lines B^2 d''' on line 4 and B^2 b on line 1, whilst the diagonal line from the end of line 1 at B to B′ in line 3 completely secures the figure.

I should here say that for practical purposes it is possible to survey this figure with the chain only by a less number of tie-lines; but seeing that I was addressing myself to a number of pupils, I dwelt with greater emphasis upon this question of tying in figures, as I wanted to prove to them that if care and judgment be observed, it is possible under almost any circumstances to make a survey by means of lines which may or may not be in the form of triangles (the former preferred where possible). I wanted to prove that the lines forming the outside or boundaries of a survey may have their relative positions one to another accurately determined by such means, and (as I subsequently show under the head of "Theodolite Surveying") if a survey be so conducted the instrumental observations will confirm the accuracy of the chain survey.

From the end of line 3, line 5 from D to E, and line 6 from E to F, line 7 from F to G, and line 8 from G to A, complete the exterior boundaries of the survey. Lines 6, 7, and 8 are fixed to the other portions of the survey by the tie-lines F A, E′ A, and E′ B^2. It will be seen that line 6 passes out of the field through a fence into the waste land adjoining the Pen-y-lan road and again into the field through the fence running alongside this road. It may suggest itself to the student that such a step might have been obviated by moving the station E further inside the field, but the object I had in view was a double one: first to show how such a difficulty of crossing a fence at a very awkward point might be overcome; and secondly, that by the trouble occasioned thereby I sought to impress upon them the fact that the reason which actuated me in taking all that trouble was to carry out my principle of reducing the length of the offsets as much as possible.

I might here explain that the dotted line B H was advisedly laid out for the purpose not only of taking a section over it, but to enable me to demonstrate the method of measuring very undulating and broken ground. In this case we had to measure across a disused quarry of nearly two chains in width, and this being partly filled with water rendered our task somewhat difficult, but it had the result of further testing the accuracy of the survey, because its intersection with the tie-lines b C, B^2 d''', and B^1 A was identical when it came to be plotted, and we had the satisfaction also of finding that on arriving on line 5 at H it measured exactly in its proper position. It will be seen that running nearly parallel east and west are two banks or mounds and a footpath shown by a dotted

SURVEY OF FIELD PEN-Y-LAN, CARDIFF.

Scale, 6 Chains to an Inch.

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line from E to B. This should be shown in the field-book by a sketch in the margin.

Foot Paths and Cart Tracks.—Foot-paths should always be shown by a single dotted line, cart-tracks by a double dotted line; but in taking the latter it is customary to ascertain the average width, the offsets of which are always taken and booked to the centre thereof unless for very exceptional reasons to the contrary.

Gates.—In picking up a gate in a fence it is necessary to fix the position of one of the posts accurately by means of a triangle and then to ascertain the width of the gate; it is not absolutely necessary to take both posts.

How to mark Hedge and Ditch.—It will be seen in the course of this survey that the fences are shown by a strong line, which indicates that it is a hedge; the little T's indicate the position of the hedge. In the case of Plate I. it will be seen that the northern and a greater part of the eastern fences are shown by dotted lines, with crossed dashes; this indicates that it is a post-and-rail fence, and where the line is firm it is evident that it is an ordinary hedge. The north-western fence F H J is a double line, from which it is to be understood that it is a wall.

Avoid crossing Fences as much as possible.—On a large survey it frequently happens that many of the lines cut through a large number of fences, but it is very desirable to minimise this as much as possible, and it not unfrequently happens that, if one stands on an eminence at the commencement of (say) line 1, it is possible to command a long stretch of country to the termination of that line, passing, it may be, through ten or twelve fields. It is wise, therefore, for the surveyor, having determined upon his stations at the commencement and termination of this line, to dispatch his assistant with laths or other means of marking, with instructions that, in front of every fence through which the line passes, he is there to leave some distinguishing mark according to directions given by means of signalling right or left, as the case may be. This should be done at every fence, for it is not at all an uncommon thing, in the process of chaining such a line, especially in a valley, that it is not only found impossible to command a view of the end of the line, but the hedges themselves may obscure the view also. But another reason in favour of marking the exact point of intersection is, that the chain-men can see the exact place througt which the chain should pass, for which purpose the offset staff has a hook arrangement (as illustrated at Figs. 1 and 2, Chap. I.) to facilitate getting it through.

Be careful not to cut Fences unnecessarily.—There are many parts of England, especially in Leicestershire, where the

hedges are not only very thick but exceedingly high; and in a survey for a railway which I made some years ago of about twenty miles in length, with the snow on the ground, my patience and that of my assistants was very severely taxed by the constant necessity of passing through such fences; and here I would repeat the warning I have given elsewhere, that the surveyor must exercise very great judgment as to how he passes through such fences. I have seen most wanton damage done to a fine, handsome, fully-grown hedge by thoughtless and often wilful cutting of huge gaps. No good surveyor would descend to such a questionable practice, and it is to obviate such expedients that I recommend the line to be accurately ranged out before proceeding to chain. Here again my theory of becoming intimately acquainted beforehand with all the characteristics of the property holds good, as, unless the surveyor has walked completely round the boundaries and made mental note of the position and form of the various fences and other circumstances, he must not be surprised if after the expenditure of some hours' work he is brought face to face with the fact that the line, which he thought would be clear of a fence running parallel therewith, at an unexpected point projects apparently right into the fence, involving a fresh line being set out and all the previous work thrown away.

Don't cut down a Tree to save moving a Line.—Again, by a reconnoitre such as I have recommended, the necessity of cutting down trees (which intercept the line) is avoided. I speak somewhat feelingly on this subject, as in one case the reckless carelessness of one of my assistants—in cutting down a valuable oak-tree in my absence—not only involved me in heavy pecuniary loss and other unpleasantness, but very nearly was the means of throwing an important project out of Parliament.

In conclusion, it only remains for me to say that when a surveyor goes on a property—no matter whether at the instance of the owner or occupier, or whether he is really a trespasser—there are certain courtesies which devolve upon him, which, if neglected, may involve him in unpleasantness if not in more serious results. If it be necessary to pass through a gate, it is equally desirable that you should close it after you; the same remark applies to doors. If curiosity prompts individuals to interrogate you as to what you are doing, a little tact may evade the necessity of your divulging your business, and protect you from the mortification of afterwards finding out that a discourteous answer was given to a person who not only had a right to know what you were doing, but who had the power to make things very unpleasant.

Clear up the Ground after you.—After having completed the survey, before leaving the ground insist upon the chain-men re-

moving all pegs and laths, which are often considered not worth carrying away, and pieces of paper that may have been used in the operations. In fact, leave the ground as nearly as possible in the state in which you found it.

Cautions.—It is not only *not* desirable to throw stones at dogs on the property, but the time occupied in so doing may be devoted to better purposes without the risk of giving offence to those to whom they belong! In putting pegs in the ground, especially in meadow land, care should be observed that they project very slightly above the surface, as otherwise serious injury is often done to cattle and horses grazing thereon.

The chain should be tested every morning before commencing operations.

If a station has been made by driving a peg into the ground, it is necessary to remove the peg if a rod is to remain there for the purpose of chaining to, as it should be exactly in the same position as the peg.

CHAPTER VI.

THEODOLITE SURVEYING.

It seems hardly necessary to say, that the long lines in many important and extensive surveys can best be ranged, and are now executed, with the theodolite or other instrument for obtaining the angles which a line or lines make with another. In Chapters II. and V. I have endeavoured to show how surveying may be accomplished with the chain only; and for small surveys in open country, perhaps the base lines are most accurately connected by chain measurements; but in the present chapter I propose to demonstrate how any large or complicated survey can only be accurately and expeditiously done by means of the theodolite.

Check-lines obviated.—In the first place we have seen that in the simple case of a four-sided figure, whose sides may have been carefully chained, it is impossible to plot the same except by diagonal or other check-lines—the only means of testing the accuracy of the work—whereas with a theodolite all check-lines are not only obviated, but in the field the accuracy of the relative positions of the four stations is made absolute by the addition of the four angles together, the sum of which should give 360 deg.

Accurately mark Station.—In commencing a theodolite survey, it is necessary to establish the chief stations in the first case, and at these points to drive stout pegs well into the ground, and into the centre of these should be driven nails to mark the exact point of intersection of the lines, which is absolutely necessary.

When to take Angles.—It is a matter entirely of choice whether the angles be taken at the commencement of the survey or not; but it will be found most convenient to take them altogether (and possibly it is preferable to do so the last thing), as it is not desirable to keep the instrument knocking about in the field, as accidents, often of a serious nature, easily happen.

The necessary Number of Angles.—I have been frequently asked by my pupils how many angles are necessary to be taken in a survey, and the syllabus of the Surveyors' Institution examination leads up to this question; so that I deem it advisable at this stage to consider the matter in detail.

In trigonometry, it is proved that to solve a triangle two angles and one side, or two sides and one angle, must be given to prove the other sides.

In the case of Fig. 187, if the side A C and the angles at A and C are given, it is possible to calculate the sides A B and B C; or if the angle B and the sides A B and B C are given, so may A C be found. Therefore in the field it is not absolutely necessary to take more than the angle B in the one case, or the angles A and C in the other,

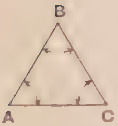


Fig. 187.

Fig. 188.

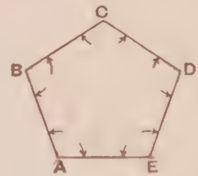


Fig. 189.

to check the accuracy of the sides A B, B C, A C; but this is a very primitive illustration, and really to do the thing properly I should recommend that *all* the angles be taken. Again, in Fig. 188, if the angles A and B are taken, then it will be possible to test the accuracy of the line B C, or *vice versa*; but here again the foregoing advice is all the more applicable. In the case of a five-sided figure, or pentagon, whilst it is absolutely necessary (Fig. 189) that the angles B, C, and D should be taken to prove the line A E, yet it seems to me to be very desirable that all the five angles should be observed, the sum of which should give 540 deg., or six right angles. Referring to Fig. 190, it will be seen that if the five angles at A, B, C, D, and E

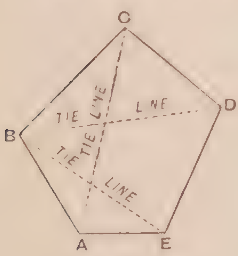


Fig. 190.

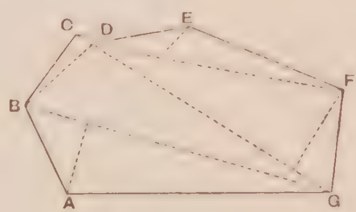


Fig. 191.

are taken, such check-lines as A C, B D, and B E (which in a chain survey would be absolutely necessary) will be obviated.

In such a figure as Fig. 191 it would be necessary to take the angles B A G, B C D, C D E, D E F, E F G, and F G A, whereby the tie-lines B G, C G, and C F would be avoided. And again, in Fig. 192, the seven angles at A, B, C, D, E, F, and G require to be observed.

It is in making a survey of a large estate that the greatest judgment is required as to what angles should be taken or not.

And as a simple illustration I reproduce a part of a survey at Cardiff (see Plate III.), executed by the pupils attending my lectures. Here it will be seen that the general outline of the estate is one of seven sides, A B, B C, C D, D E, E F, F G, and G A, whilst the four indentations are dealt with by small triangles *b* A B, *d c d''*, and D J E. Although this is only a sketch from memory, yet it is fairly proportional, and serves to illustrate how the long offsets on lines A B, B C, C D, and D E were avoided. I do not say that the angles of these four small triangles should not be taken—indeed if time permitted it would be very desirable to do so—but I offer this sketch as a type of those angles which should be taken and which may be avoided.

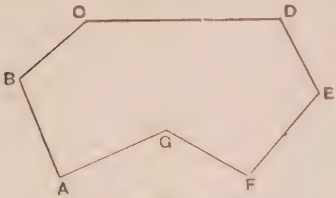


Fig. 192.

Angles necessary.—Thus angles 1, 2, 3, 4, 5, 6, and 7 are indispensable to the accuracy of the survey, whilst the four triangles may be treated in the ordinary way. So in the survey of an estate, large or small, a similar treatment will be found desirable.

Requirements by the Examiners of the Surveyors' Institution.—In the instruction to candidates, under the head of "Land Surveying and Levelling," issued by the Surveyors' Institution, each candidate is required to make a survey by himself of from 15 to 20 acres, "comprising not less than four separate fields or enclosures, and having a minimum variation of 5 ft. in the surface level, and to take the angles of the principal enclosing and check-lines with the theodolite, entering them in the proper place in the field book." This extract serves to enable me to illustrate my contention.

First a Chain Survey.—The examiners of the Surveyors' Institution, for the purpose of testing the general knowledge of the candidate in surveying, very properly require him to first make a complete chain survey of the property, and having done this he is to test the accuracy of his work by observing the angles of the enclosing and check-lines. But my contention is that the theodolite entirely obviates the necessity for tie-lines except, as I have before stated, where triangles are used to avoid long offsets.

I have endeavoured to explain as clearly as possible the system that should govern a theodolite survey. But before I proceed to explain Plate No. I., which appears to me to be as good a type as possible, I would here introduce one or two examples taken from the works of other authorities on the subject, to illustrate what I venture to think are the fallacies of surveying.

What to avoid.—In Fig. 193 I reproduce an example given in an old work upon surveying which, I think, will illustrate what to avoid in theodolite surveying. It will be seen that by a more judicious use of the instrument the irregular boundaries of this

Fig. 193.

property might have been more accurately determined than by the system illustrated.

We have an estate consisting of three large and one small and irregularly formed fields encompassed by fourteen main

survey-lines. I have reproduced (Figs. 194 and 195) the field-book of lines 1, 2, 3, and 4. Now, commencing line 1, we have the angle

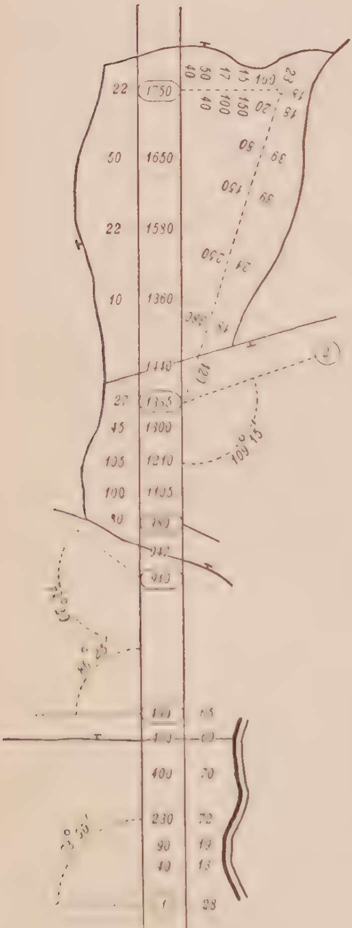


Fig. 194.

Fig. 195.

which line 11 makes with it, viz. 73 deg.; and at 490 we have line 5 making an angle of 86 deg. 25 min. with line No. 1; and at 910 line No. 9 makes an angle of 78 deg. 20 min. with line No. 1; but at

980, the station for line No. 4 on the right, it is not deemed necessary to take this angle, nor indeed is line No. 4A regarded as sufficiently important to have its position fixed with the theodolite. It is true that from 490 and 980 in line No. 1 the lines 4A and 4 have at 175 in the former, and at 222 in the latter, a check-line of 160; but the importance of having the meandering stream accurately fixed would surely justify, whilst the instrument was fixed at 490, to observe line No. 5, to have taken the angle of the line 4A. Now instead of forming two stations close together on line No. 1 at 910 and 980 for lines 9 and 4 respectively, by slewing line 9 round (which would be more convenient for the small fence), we should have only one instead of two stations for lines 9 and 4, and the angles formed by lines 9 and 4 respectively with line No. 1 could be taken at the same time. At 1335 in line No. 1 we have line No. 2 making an angle of 109 deg. 15 min., but instead of the small triangular field being fixed by the line 22 deg. 40 min. from 1335 in line No. 1 it would have been quite as well to check the actual position by finding the intermediate angle, without which I am of opinion the position of this triangular field is not sufficiently reliable. So much for what angles have been taken. I now turn to those that have been omitted, and which in my judgment are essential to the satisfactory and indeed accurate completion of the survey. The angles between lines Nos. 2 and 3, 3 and 4, 4 and 4A, 5 and 10, 5 and 6, 7 and 8, 10 and 11, and 1 and 4.

Surveying a River.—In surveying a river, I do not know that I can suggest a better method of recording its serpentine course, than that suggested in Fig. 196. Here, we have line No. 2 forming an angle of 95 deg. 38 min. with No. 1, line No. 3 forming an angle of 61 deg. 50 min. with No. 2, line No. 4 forming an angle of 43 deg. 40 min. with No. 3, and line No 5 forming an angle of 51 deg. 5 min. with No. 4. The various small triangles on lines Nos. 2, 3, and 4 required for the purpose of taking up the bends of the river will serve as additional checks to the work.

Don't spare the Use of the Theodolite.—Thus I trust I have established a rule that the theodolite, when once called into requisition on a survey, should not be used sparingly, but all the chief lines, constructing as it were the main network, should be systematically connected by means of ascertaining their various included angles.

Corroboration of Observation.—What can be more satisfactory, to take a simple illustration, than to find the sum of three observed angles of a triangle make 180 deg.; and much greater corroboration of your work in the field will attend such a number of angles as

Fig. 196.

will give a similar result, as I have shown in a preceding illustration.

Now let me guard against any possible misinterpretation of my meaning in the foregoing paragraphs. There are cases, as in Fig. 197, where it is quite unnecessary to take more than the six angles, A, B, C, D, E, and F, which govern the lines which absolutely affect the external boundaries of the estate, such as 1, 2, 3, 4, 7, and 8. The truncated cone formed by lines 1, 2, 3, and 4 should give by the sum of the angles A, B, E, and F 360 deg., whilst the angles C and D serve to determine the exact position of a portion of line 3 and line 7.

Line 5, by reason of each of its extremities being fixed by the chainage on lines 2 and 4, should by its length be an additional check of the accuracy of the survey, whilst it serves to pick up the fence which runs alongside it. The same applies to line 6, whilst if the angles C and D and the lines 3 and 7 have been accurately taken and plotted, then line 8 should exactly fit in at their extremities.

By reference to Plate

No. I. it will be seen that a portion of my ground at Wimbledon Park is here delineated to illustrate the method of testing a chain survey. The estate, bounded on the east and south by a wood, on the west by roads, and the north by a plantation, has been surveyed by chain only on the lines 1, 2, 3, 4, 5, 6, 7, 8, and 9 with the various check-lines as shown. Now, having thus made an accurate chain survey, it was desirable to show my pupils how I should have proceeded with a theodolite, and at the same time to check the other work. The following angles were necessary: D A B, A B C, C B E, B C D, J H D, and C D A, by means

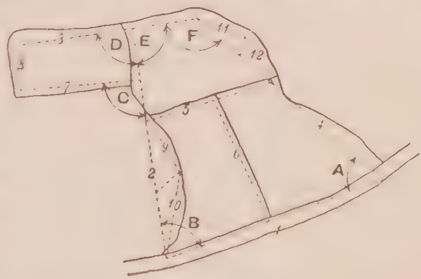


Fig. 197.

of which it was shown that the tie lines D B, *a* A, E *e*, C G, and H *h* were obviated. As under the head of "Traversing" I shall have to deal with that part of this survey which has reference to the roads in the wood, I shall not at the present say anything about them. I have reproduced the field-book in connection with this survey, which will better illustrate its *modus operandi*.

A few brief hints as to the practical part of theodolite work will form a useful conclusion of this chapter.

Hints on the Use of the Theodolite.—1. It is of little use attempting to use the theodolite on a foggy, rainy, or windy day. I need not dilate on my reasons in the first-mentioned case; but in the second, the wet gets into the glasses, and the constant necessity to take them out and wipe them is not only a source of delay but a very great tax on patience; and with regard to wind, not only does it affect the steadiness of the telescope, but the chief difficulty is to keep the plumb-bob from swaying about, and unless it is perfectly plumb over the nail or cross-cut the accuracy of the observations will be impaired.

2. Before planting the instrument see that the point of the plumb-bob is exactly over the point of intersection of the line.

3. Always plant the legs of your instrument firmly in the ground as nearly level as your judgment directs. Don't force all three legs in at once by pressing from the apex, but take each leg separately, and with both hands press it into the ground.

4. Having "planted" the instrument, before you proceed to level it, take care to clamp the upper plate to the lower one at zero.

5. Now level the instrument by means of the parallel screws,

having previously attended to the adjustments for collimation, parallax, &c (referred to in Chapter III.).

6. Now direct the telescope in direction of the extremity of the first line which forms the angle as B (Fig. 198), and when as near upon the point as is possible, clamp the lower plate and bring it exactly to allow the cross-wires to intersect the point B by means of the lower tangent or slow motion. NOTE.—Do not on any account touch any other than the lower clamp and tangent screws in this operation.

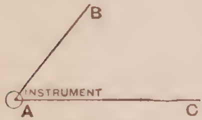


Fig. 198.

7. Now (having entirely done with the lower clamp and tangent screws) unclamp the upper plate and gently turn the telescope in direction of C, then clamp it at as near the point as possible, and with the upper tangent or slow-motion screw bring the cross-wires until they exactly intersect the point C.

8. Now proceed to read the number of degrees and subdivisions of degrees on the lower plate, and the number of minutes and subdivisions in the vernier.

9. Always take the lowest point of a rod, and preferably the point of it, or an arrow held upon the nail or cross-cut in the peg. In the case of a church steeple it is advisable to take the apex.*

10. The observer should not talk or be listening to conversation during instrumental observations, as the distraction of his attention often leads to serious mistakes.

* Chesterfield church excepted.

CHAPTER VII.

TRAVERSING.

WHILST surveying proper is entirely dependent upon a system of triangles or other figures, whose sides must be accurately measured, and whose relative points of intersection must be tied in with the greatest care, traversing may be termed a method of following the meandering of any irregular figure, whose sides shall be determined by angular observation.

Traversing with Chain.—Traversing may be accomplished with a chain only, but this mode of proceeding is open to great objection, as inaccuracies may find their way into the work itself, and there is no real security for its accuracy.

I illustrate by Fig. 199 the general principles of a chain traverse, and I think it will be manifest to those who have read the preceding chapters that little or no dependence should be placed upon the relative positions of lines to each other, which rely solely upon the measurement of a short length at the extremities of lines. Take the lines A B, B C, C D, D E, and E F (Fig. 199), whose directions are entirely dependent upon the care with which the triangles *a b* B, *c* C D, D *d e*, and E *f g* are taken, and not only as affecting the measurement upon the ground, but more particularly the after operation of plotting; for, unlike a chain survey of a series of triangles and check lines, there is nothing in a chain traverse to guarantee the accuracy of the work. Upon fairly level ground, in the enforced absence of instruments, it may be admissible to ascertain the relative positions of diverging lines by some such method, to do which even I should strongly advise the use of an optical square to establish the triangles, which, wherever practicable, should be *right angled*; but in undulating ground I do not hesitate to say that chain traversing is inadmissible.

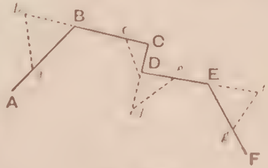


Fig. 199.

Traversing by Included Angles.—Traversing may also be performed by taking the included angles A B C, B C D, C D E, and D E F (Fig. 199) either with a box-sextant or, preferably, a theodolite. These angles having been accurately observed, and the lengths, A B, B C, C D, D E, and E F carefully

Fig. 200.

measured, the survey may be plotted with a straight-edge and

protractor, but the greatest minuteness is necessary, for it is only what is called an "unclosed" traverse.

The most generally adopted system of traversing is by observations from magnetic north, as is illustrated in Fig. 200, which is an unclosed traverse; in other words, the survey has no means of being adjusted to its starting point, either from real cause or option. If we were to take such a figure as an octagon (Fig. 201), and work all round its eight sides at the points A, B, C, D, E, F, G, and H, then, if we had observed the necessary care in taking the angles, when we closed from H upon A we should find our work prove itself. But in the case of Fig. 200, which is the traverse survey of a meandering road on either side of which are dense

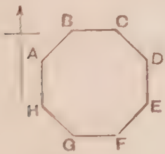


Fig. 201.

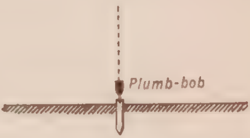


Fig. 202.

plantations, in terminating our work at F we have nothing to guarantee its accuracy, as it is impossible to command the starting point A, which, if we could do so, would enable us to test our work.

Now, in commencing a traverse, or any operations in which the compass is used, it is imperative to guard against any metallic attraction, as even with the most studious care traversing is a very delicate process. It is necessary to carefully select your stations, and by means of pegs or other means to mark the various points, such as A, B, C, D, E, and F; the measuring the lines between these points, together with the necessary offsets right and left, may be accomplished in the first case or subsequent to the instrumental observations, but the one operation should be distinct from the other. Possibly it would be more convenient to have made the survey first, so that the angles and other information may be neatly entered in the book in their proper order and place. It should be here noted that after the instrument has been adjusted, the upper and lower plates being clamped at zero (and duly levelled, care having been taken to firmly plant it exactly over the point of intersection of the line *), and when the zero of the upper and lower plate have been made to coincide with magnetic north, that the lower plates should be firmly clamped, and on no account must

* This is best accomplished by driving a brass-headed nail in the centre of the peg, and let the point of the plumb-bob be coincident with it. See Fig 202.

it be touched either by accident or intent, otherwise the work will be in error. Now having taken all these necessary precautions, the instrument being placed at A (Fig. 200), direct the telescope to a rod held on the peg at B, being careful that the wires intersect the spike of the rod. In the illustration before us the angle which B makes with magnetic north at A is 50 deg. on the A vernier and 310 deg. on that at B; * now remove the instrument to B, with the upper plate still clamped at 50 deg., and, after having adjusted it, direct the telescope back to A, and by means of the tangent screw see that the wires exactly cut the bottom of the rod.

Plenty of Assistance required.—Here let me say that plenty of assistance is required in traversing, as I am opposed to leaving a rod either stuck in the hole of the peg or behind the peg itself, either of which in the case of road or town surveying is impossible. Consequently I prefer that the spike of a rod should be held by an assistant on the point of the peg. Having intersected the point A, unclamp the upper plates and bring it to zero; the result should be that the needle will record magnetic north, if not, something wrong has occurred, which must be attended to at once, even to the commencement *de novo*. Having satisfied ourselves that the needle is in its normal position, unclamp the upper plate and turn the telescope to C, which will give 135 deg. or 85 deg. from magnetic north. Keeping 135 deg. in the instrument, remove it to C, observe back upon B, bring the top plate to zero, and the needle should again assume magnetic north. Next direct the telescope to D, when the reading will be 282 deg. or 147 deg. from magnetic north, and so proceed at the points D, E, and F; the various angles should be entered as follows:—

$$\left.\begin{array}{l} A = 360^\circ \\ B = \ \ 50^\circ \end{array}\right\} 2100 \text{ links.}$$

C = 85°	2880	,,
D = 147°	1400	,,
E = 82°	2780	,,
F = 143°	2150	,,

Northings and Southings.—Now in plotting the foregoing it is necessary, to ensure accuracy, to draw a series of vertical and horizontal lines intersecting the various points, and really converting them into a series of right angled triangles, whose base and perpendicular are the sines and cosines of the complements of the various angles; they are also designated "northings" and "southings" for the perpendiculars, and "eastings" and "westings" for the horizontal lines. In the first case draw the vertical line representing magnetic north at the point A. Now we have seen that

* Most theodolites have their vernier marked A and B, the former being used to take the angle proper and the latter as a check.

the sine and cosine of the complement of an angle will give us the lengths of the base and perpendicular as A a, a B (Fig. 200), therefore $90° - 50° = 40°$, and the natural sine of 40° is ·64279, which, if multiplied by the length A B = 2100, will give 1,349 links as the length a B; and the cosine of $40° = ·76604 \times 2100 = 1608$ = A a. Again, B C makes an angle of 85° with magnetic north, consequently $90° - 85° = 5°$, then nat. sin. $5° = ·08716 \times 2880 = 251$ = b C, or nat. cos. $5° = ·99619 \times 2880 = 2869$ = B b. Now if the angle be greater than a right angle it must be deducted from 180 deg., and if greater than two right angles then from 270 deg., and if greater than 270 deg. from 360 deg. Thus in the case of D the right angle being 147 deg., we must deduct it from 180 deg.; thus $180° - 147° = 33°$, and nat. sin. $33° = ·54464 \times 1400 = 762$ = d D, nat. cos. $33° = ·83867 \times 1400 = 1174$ = d C; and in like manner all the various sides may be calculated which are tabulated as under :—

		HYP.	BASE.	PER.
A B	$90° - 50° = 40°$	2100	1608	1349
C	$90° - 85° = 5°$	2880	2869	251
D	$180° - 145° = 33°$	1400	762	1174
E	$90° - 82° = 8°$	2780	2752	367
F	$180° - 143° = 37°$	2150	1293	1717

But these calculations are not alone sufficient to ensure accuracy, as it is necessary to treat an enclosed traverse somewhat in a similar manner to plotting a section. Referring again to Fig. 200, it will be seen that f E is 1717, and e E is 367, therefore $e\,f$ is $1717 - 367 = 1350$; now $d\,e$ are in the same plane, consequently $a'\,d$ is 1350, and d C is 1174, whilst $d\,b$ is $1174 - 251 = 923$, and b B is parallel to A a, therefore $a''\,d + d\,b = 1350 + 923 = 2273 = a'$ B; consequently if we mark on the line A′ F the horizontal distances A a', $a'\,a''$, $a''\,a'''$, $a'''\,f$, and f F, which are 1608, 4477, 5239, 7991, and 9281, and then plot A′ A = 924, a' B = 2273, a'' C = 2524, a''' D = 1350 f E = 1717, we shall have satisfactorily accomplished our traverse, and assured ourselves as to its accuracy. If it be possible, with the instrument at F, to command a station at A′, then taking the last angle, viz. 143° from 180° = 37°, consequently E F A′ = 53°; if, therefore, from F 53° be set from E towards A′ it should give a point 924 links below A, which is of course an important check equally as the length A′ F could it be accurately chained, which would give 9,284 links.

As to closing a Traverse.—Of course, if it is possible, it is always desirable to close a traverse, even to the extent of working back to your starting point by a circuitous route, as illustrated in

Fig. 203, whereby, after having accomplished from A to F, which was work requiring to be done, it would be satisfactory to continue back to A by the zigzag route F G, G H, H J, J K, and K A; and

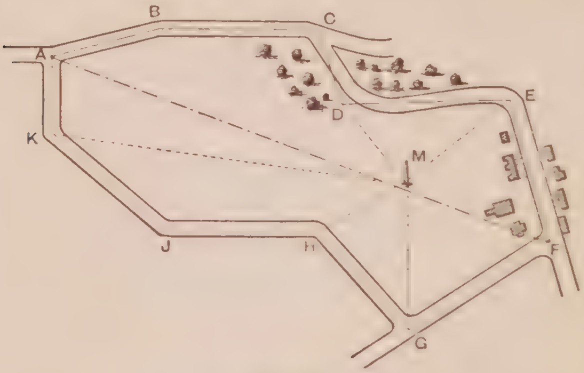


Fig. 203.

although it would be more satisfactory to have the lengths of these lines as well as their bearings, yet it is not absolutely necessary, as the sum of the angles will give, if the observations be carefully taken, the result of working back on to A as we commenced. By such a method the necessity of calculating the sines and cosines is obviated.

Care in Checking.—In taking angles from magnetic north it is necessary to be very careful that the readings are correct; and as an additional check upon the work, especially in a close survey, it is desirable to take frequent objects, such as the chimney at M in Fig. 203, to which observations may be made at the points D, E, F, G, H, and K.

Relative Position of Bearings.—In booking the bearings, it is desirable to have them in their proper order. For instance, all angles less than 90 deg. will be N.E.; between 90 deg. and 180 deg. S.E.; between 180 deg. and 270 deg. S.W.; and between 270 deg. and 360 deg. N.W. When it is possible to take the included angle between points such as E F G (Fig. 203), it is, of course, very desirable to do so.

Magnetic Variation.—It is necessary to make allowance for what is termed the magnetic declination or variation, which alters every year. At the present time (1893), at the Royal Observatory, Greenwich, the variation is 17° 12′ west, and diminishes at the rate of seven minutes annually. It is needless to say that this varies with the geographical position of the point of observation

CHAPTER VIII.

TOWN SURVEYING.

To make a survey of a town or even a village is by no means an easy task, added to which it is a very tedious proceeding, for it seldom happens that lines of any great length can be arranged. It is desirable, however, that when possible a base-line should be taken through the town from end to end, in order to tie all the other lines on to it. Triangulation is almost impossible, owing to the irregularity of the streets. It is equally out of the question to do town surveying without an instrument for taking the angles of the various lines.

The surveyor should provide himself with a skeleton plan of the principal thoroughfares, upon which he should lay out such lines as appear to him feasible and then proceed to examine them upon the ground. Having determined upon some of the chief lines, he should establish stations, where possible using hydrants or sewer-ventilators to mark the spot. In the absence of such, he will have to drive down iron spikes or "dogs" into the pavement, for which

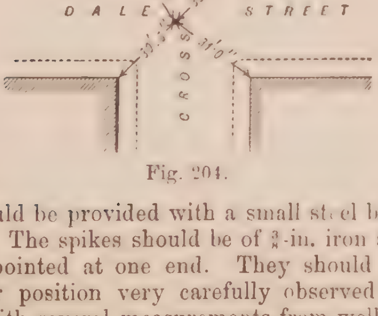


Fig. 204.

purpose he should be provided with a small steel bar and a fairly heavy hammer. The spikes should be of $\frac{3}{8}$-in. iron and from $2\frac{1}{2}$ in. to 4 in. long, pointed at one end. They should be driven well home and their position very carefully observed by means of a detail sketch, with several measurements from well-defined points. as in Fig. 204, taking distances from the four angles of Cross Street

and Dale Street; or, as in Fig. 205, with two distances from the angles of Church Lane and High Street and from the end of the "Crown Inn" on one side, and from a point measured along the

Fig. 205.

face of the hotel from George Yard; or, in Fig. 206, from the two angles of the Market Place and those of Market Street.

It is recommended by some writers to take "lamp-posts, corners of buildings, &c.," as "objects at a distance," forgetting that inasmuch as instrumental observation will be necessary at all points of divergence, such points will be of very slight service, inde-

Fig. 206.

pendent of their somewhat questionable applicability. Town surveying requires great care and patience, with a very considerable amount of method. It resolves itself into three distinct operations after the lines and stations have been determined: 1, the observation of the angles; 2, the chainage of the lines between these points; and 3, the detail measurement of the yards, gardens, buildings, &c.

Taking Angles.—There are two ways of taking the angles.

First by taking (with theodolite or prismatic compass) the angle which a street or road makes with the magnetic meridian, but which cannot be recommended in towns (although in villages it may be more practicable), in consequence of the numerous sources of attraction to the needle, such as tram-rails, lamp-posts, hydrants, man-holes, iron railways, &c. By the second and most reliable method the included angles of one or more lines are taken with the theodolite as illustrated in Fig. 207, where a line along Station Road terminates at the junction of three streets. Here the theodolite should be planted, and after being carefully adjusted, the angle between Station Road and High Street (90° 30′), between High Street and West Gate (71° 00′), and between West Gate and Mill Street (46° 00′), should be observed; the sum of which

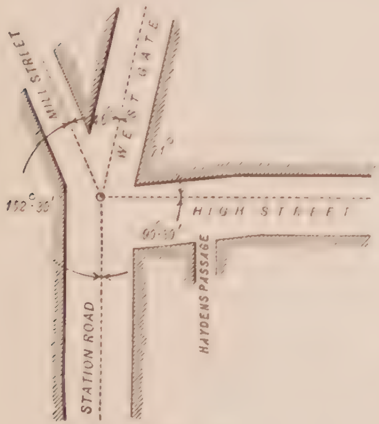


Fig. 207.

Fig. 208.

should be 207° 30′. Now take the angle between Station Road and Mill Street, which should be 152° 30′, or the difference between 360° 00′ and 207° 30′.

Objection to Lamp-posts, &c.—My reason for *not* taking lamp-posts, corners of houses, &c., as distant points upon which to fix the telescope, is that in the first place they can only be of a temporary character, and a lamp-post especially is not sufficiently defined for the purpose even if it be perfectly perpendicular. If spikes are driven in the streets or roads at points of intersection, it is surely the most accurate method for a chain-man to hold the point of the rod upon the spike, which point is only to be taken, for I cannot impress upon the student too strongly the necessity of observing the bottom of the rod as in Fig. 208 in *all* surveying

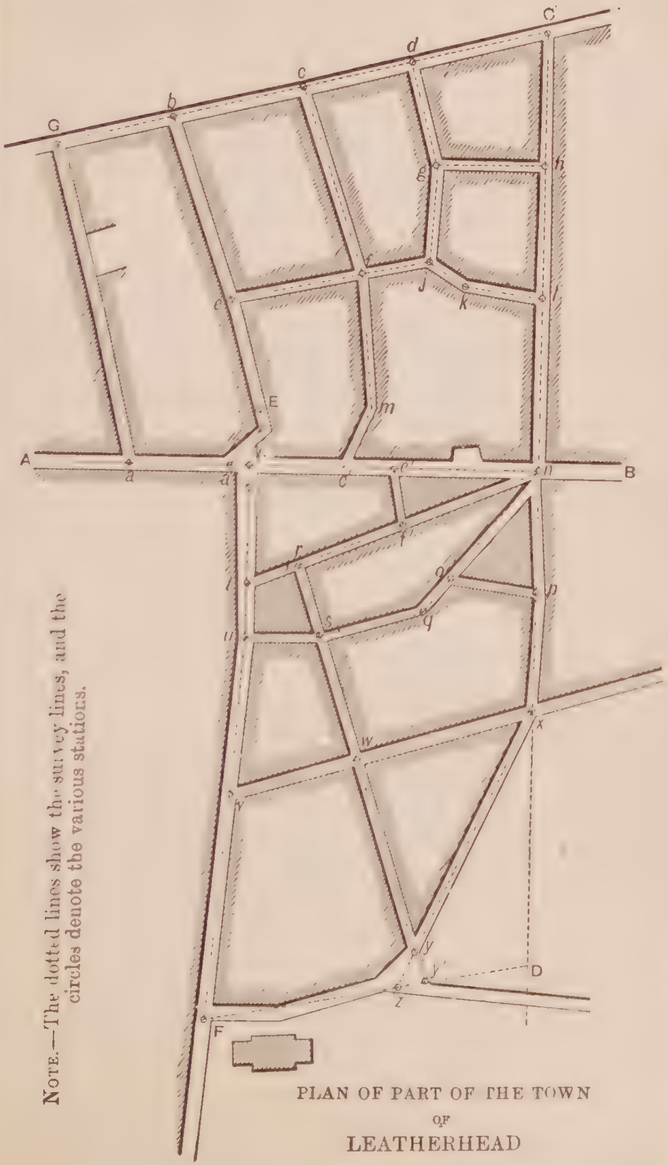
Fig. 209.

operations, whether it be simple chain-surveying or with a theodolite. By this means we have an absolute point upon which our instrument will in turn be placed, so that with necessary care all our observations should be accurate, and judgment (often very misleading) as to which is the actual centre of a far distant lamp-post is obviated.

In consequence of the circuitous nature of many streets in European towns—which, unlike American cities, were evidently never laid out with any idea that it would be necessary to survey them—it is often impossible to get a straight line from end to end. Take the case of Fig. 209. Here we have, at A, to take the two angles right and left equal to 180°. At B we should take the angle between A and Bemer Street, and that between Bemer Street and C, whilst to test our work we must observe the angle C B A, all three being equal to 360°; at C, the included angle B C D and its supplement at D, all four angles which should equal 360 deg.

Now a very natural question might be asked: "Yes, I see how you do such a street, and if I have taken the angles and distances between the points correctly, all well and good: but how do I know that it will all fit on to the other parts of the survey?" I will endeavour to clear this question up.

In Fig. 210 we have a sketch map of part of the town of Leatherhead, of which it was desired to make a detailed survey. It was found impossible to run a larger base-line through the principal streets than the line A B, about 1,200 ft.; but C D, 2,050 ft. could be tied on to the other portion of the survey outside the



NOTE.—The dotted lines show the survey lines, and the circles denote the various stations.

PLAN OF PART OF THE TOWN
OF
LEATHERHEAD

Fig. 210.

town, and as it is always best to take the longest line for a base we adopted C D. It so happened that A B is so situated that it was possible to set out the line at right angles to C D, which of course was of immense advantage. But with the exception of the short line $g\,h$, this is the only case in which it was possible.

Taking the upper portion first, it will be seen that G C at the ends of C D and of a G with A B circumscribed this portion of the town; on the line A B, stations at a, a', b', c', e', and n were left, whilst on G C, stations b, c, and d; and on the upper part of C D, h and l.

Strictly speaking, the angles a G C and G C D should be taken as well as G a B and C n A; although it is argued that if these latter two angles are accurately taken, and the distances G a, $a\,n$, and n C are carefully measured, then by calculation in the one case and measurement in the other the length G C will be proved. I say it is so argued, but my own opinion is that whilst about it the most satisfactory way will be to take the angles with the theodolite, especially as we must take the angles G $b\,e$, G $c\,f$, G $d\,g$. It is not absolutely necessary to take the angle $b\,e\,f$, but those $c\,f\,j$, $f\,j\,g$, $g\,j\,k$, and $k\,l$ C are imperative; as are also A b E and A c' m, the angle A a' E is not necessary, but the line a' E should be carefully measured as a tie; $g\,h$ need only to be measured from their respective points and will act as a check on $d\,g$ and $c\,h$.

Similarly, if the angles A b' F and A n D be carefully observed in the lower portion, it is not absolutely necessary to take more than $b'\,t\,n$ and $u\,s\,q$, as all the other lines tend to check the trapesium b' F D n; for $t\,n$ and $v\,x$ in one direction and $r\,y'$ and $x\,z$ in the other are as complete checks as can be wanted.

Thus will be seen the relative systems to be adopted in street surveying, but let it never be forgotten that there should be no question about the angle any street may form with another. The line C D was able to be produced until it fitted into the system of triangulation for the survey of the district around the town.

The traffic in the streets is a considerable drawback to the operations of the surveyor, whilst from twelve till two and after four o'clock are periods towards which he looks with dread, as at these times he is sure to be accompanied or surrounded by a powerful contingent of the rising generation, whose inquisitiveness and love of mischief are of the greatest impediment to his progress, and test his patience and temper to the utmost.

As to the Chain.—For ordinary small scale plans the measurements may be taken with a 66 ft. chain, but when great detail and accuracy are requisite the 100-ft. chain is the best. The offsets should be taken in feet and inches with a tape; those at right angles to the chain-line require the greatest care and are best set out with an ordinary square (as it is seldom, from the narrowness

of the streets, that an optical square can be used) having one arm 6 ft. and the other 4 ft. long (see Fig. 211). This should be laid on the ground and adjusted until the long arm is in line with the point to which the offset is to be taken. But it is not sufficient to

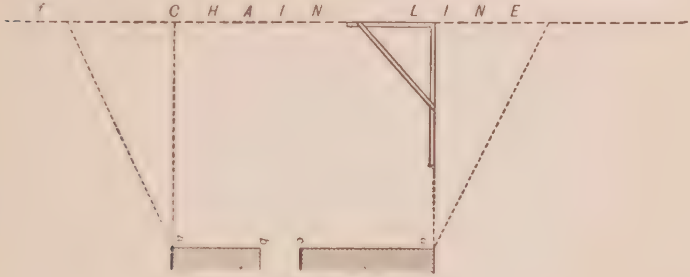


Fig. 211.

trust to such offsets to fix the corners or angles of buildings. A tie-line is necessary, as in sketch.

It is very seldom that the frontages of streets are straight or that they are of equal width. It more frequently happens that indentations of all kinds occurs as in Fig. 212, where it will be seen that in order to accurately take up the various angles and indentations a very elaborate network of triangulation is necessary, as shown by the dotted lines.

It is not sufficient at the angles formed by one street running out of another to take an offset at right angles, and form a right-angled triangle as a check. It is necessary to make an independent triangle such as Δ *b c*, Δ *a b*, Δ *c d*, Δ *e d*, Δ *e f*, Δ *g f*, Δ *g h*, or Δ *h a* in Fig. 213.

The diamond formed by those triangles which are hatched need not necessarily be taken, but it is quite as well to have the thing complete, especially at important points.

When the outlines of the streets have been surveyed and plotted, the surveyor should make a careful tracing of sections of the work, and then carefully walk over the route to examine every detail, so as to be satisfied that nothing has been omitted.

Then a station plan, drawn to a large scale, should be prepared and mounted, in sizes of about 18 in. square, on a board, so that the details of the houses and outbuildings may be accurately drawn to scale as the measurements proceed. A steel tape or a 10-ft. rod is the best thing for this purpose.

When to take Angles.—In busy thoroughfares it is always desirable to take the angles soon after daybreak, so that the operations may not be impeded by the traffic.

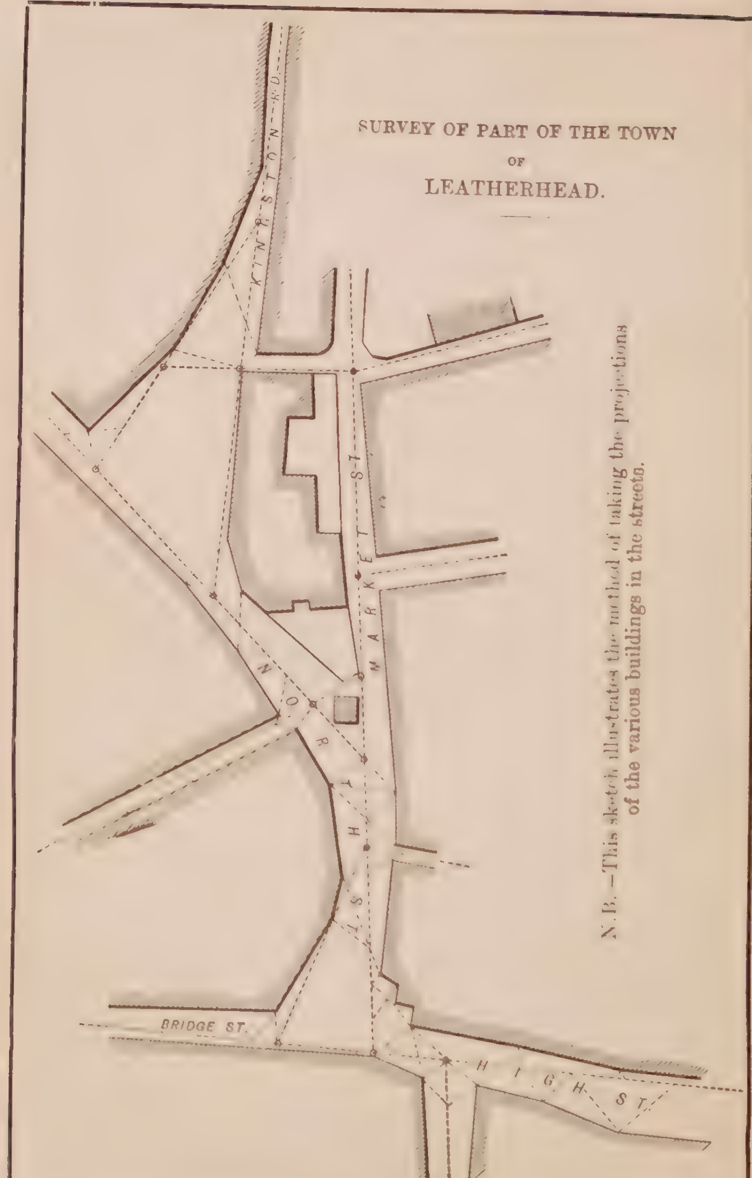

SURVEY OF PART OF THE TOWN
OF
LEATHERHEAD.
KINGSTON RD.
MARKET ST.
NORTH ST.
BRIDGE ST.
HIGH ST.
N.B.—This sketch illustrates the method of taking the projections of the various buildings in the streets.

Fig. 212.

In measuring buildings the greatest care is necessary to see that the total length of a series of frontages is equal to the sum of the separate frontages. For this purpose the addition should always be made on the side of the field-book or upon the detail drawing, and in ink if possible.

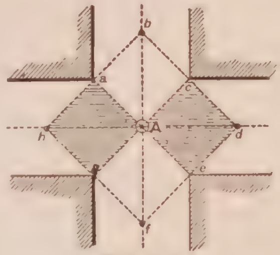


Fig. 213.

Do not erase Figures.—In all branches of surveying it is important to bear in mind that figures when once written down should on no account be erased, but if it is necessary to alter them then draw the pencil through the existing figures and over or by the side make the alteration. I have seen some very serious mistakes occur by rubbing out figures which after all have proved to have been right.

If you cannot drive a peg or spike into the road, as in the case of asphalte roads, then the intersection of lines should be arranged so as to cut at some point on the curb or pavement, in order that a rail or spike may be driven in at a joint.

Use Arrows for counting.—In measuring a line along a street an arrow should be stuck in if possible, or if not, it should be left to denote the number of chains, and the leader (who should always have plenty of chalk about him) should mark with a "crow's-foot" the end of the chain together with the number, with chalk, either upon the pavement or on the walls of the buildings.

As to Buildings.—Outhouses should be specified in the field-book. Churches, chapels, schools, and all public buildings should be carefully noted. Also public-houses, beer-houses, "on" and "off" licences, &c.

Lamp-posts, Gullies, &c.—The position of lamp posts, gullies, ventilators, sluice-valves, hydrants, manholes, &c., must be taken up *en route* and carefully plotted on the plan.

As to Streams.—Should a street or road cross over a river or stream the full particulars thereof must be noted; and by an arrow the direction of the flow should be indicated. Or in the case of a railway crossing over or being crossed by a street, the name and particulars of the railway, together with the direction of its commencement and termination, should be ascertained and marked upon the plan. The nature of the street or road should be observed—whether gravel, macadam, granite-pitched, wood, asphalte, &c. And the pavement, whether York paving, artificial stone, asphalte, concrete, brick-on-edge, gravel, &c. The boundaries of the various parishes must be ascertained and carefully plotted, even in such a

caso as occurred to me at Hereford, where I found that the intersections of three parishes occurred in one of the bedrooms of a school-house. The parliamentary or municipal boundaries, or those of wards, must also be shown. Each road or street must be plainly marked with its name, and the thoroughfares at the outside of the survey should have written in italics the places to or whence they lead.

As to Plotting.—The survey of a town or parish should *always* be plotted so as to be north and south; in other words, the top of the sheet is north and the left and right sides are west and east respectively.

CHAPTER IX.

LEVELLING.

LEVELLING is the art of finding the difference between two points which are vertically at different distances from a plane parallel with the horizon. Take the ocean or a sheet of water, the calm surface of which is in a parallel plane with the horizon, then the bank or beach that is above the water-line at certain points is relatively higher in level than the water itself. Thus in Fig. 214, where A represents the impingement of the water upon

Fig. 214.

the slopes of the stream, B is relatively higher, and C and D lower, than the horizontal line L L′.

This is a very primitive description of what levelling means, but it is nevertheless a true one.

As to the Earth's Curvature.—But there is a very important consideration in reference to this question, and that is, that the earth being spherical in form, strictly speaking two points are only truly level when they are equidistant from the centre of the earth.

Also, one place is higher than another, or out of level with it, when it is further from the centre of the earth ; and a line equally distant from that centre, in all its points, is called the *line of true level*. Hence, because the earth is round, that line must be a curve, and make a part of the earth's circumference, or at least be parallel to it and concentrical with it, as the line P F D B C E Q (Fig. 215), which has all its points equally distant from A, the centre of the earth, considering it as a perfect globe.

But the line of sight F′ D′ B C′ E′, given by the operation of levels, is a tangent or right line perpendicular to the semi-diameter of the earth at the point of contact B, rising always higher above

the true line of level the farther the distances, and is called *the apparent true level.* Thus C′ C is the height of apparent above the true level, at the distance B C from B; also E′ E is the excess of height at E. The difference between the true and the apparent

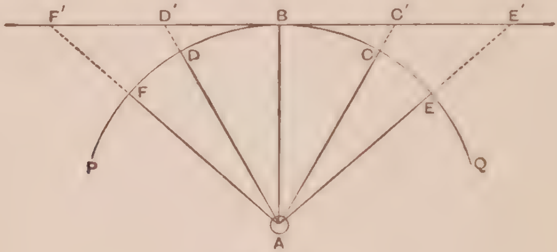


Fig. 215.

level, it is evident, is always equal to the excess of the secant of the arc of distance above the radius of the earth.

Now the difference C C′ between the true and apparent level, at any distance B C or B C, may be found thus: by a well-known property of the circle $2\ \text{A C} + \text{C C}' : \text{B C} :: \text{B C}' : \text{C C}'$; or because the diameter of the earth is so great with respect to the line C C′, at all distances to which the operation of levelling commonly extends, that 2 A C may be safely taken for $2\ \text{A C} + \text{C C}'$; in that proportion without any sensible error, it will be, as $2\ \text{A C} : \text{B C}' :: \text{B C}$ to C C′, C C′ therefore $= \dfrac{\text{B C}'^2}{2\ \text{A C}'}$ or $\dfrac{\text{B C}^2}{2\ \text{A C}}$ nearly; that is, the difference between the true and apparent level is equal to the square of the distance between the places, divided by the diameter of the earth: and consequently is always proportional to the square of the distance.

	Stat. miles.	Feet.
Now the polar axis of the earth is	= 7899·155	= 41,707,536
Mean equatorial diameter	= 7925·694	= 41,847,662
Or a mean of	7912·974	= 41,777,599.

Allowance for Curvature.—Therefore $41{,}777{,}599 \times 12 = 501{,}331{,}188$ inches.

Now take the distance as one mile or 63,360 inches. Then—

$$\frac{\text{B C}^2}{2\ \text{A C}} = \frac{63{,}360^2}{501{,}331{,}188} = \frac{4{,}014{,}489{,}600}{501{,}331{,}188} = 8 \text{ inches in one mile,}$$

which is the difference between the apparent and true level.

The following table, based upon the foregoing formulæ, gives results for the difference between apparent and true level from 100 yards to 10 miles.

Distance, or B C.	Dip of Level, or C C′.	Distance, or B C.	Dip of Level, or C C′.	
Feet.	Inches.	Miles.	Feet.	Inches.
300	0·026	$\frac{1}{4}$	0	$0\frac{1}{2}$
600	0·103	$\frac{1}{2}$	0	2
900	0·231	$\frac{3}{4}$	0	$4\frac{1}{2}$
1,200	0·411	1	0	8
1,500	0·643	2	2	8
1,800	0·925	3	6	0
2,100	1·260	4	10	7
2,400	1·645	5	16	7
2,700	2·081	6	23	11
3,000	2·570	7	32	6
3,300	3·110	8	42	6
3,600	3·701	9	53	9
3,900	4·344	10	66	4

Thus if the staff be 600 feet from the instrument, and the cross-wires cut 10·50 feet, we must deduct 0·103 inches from this height, which should now be 10·39.

10·49

Refraction.—There is also another matter that has to be considered, and that is "atmospheric refraction." The line of sight, being the line along which the light proceeds from the object looked at to the telescope, is not perfectly straight, being made slightly concave downwards by the refracting action of the air. Hence the point seen on the staff apparently in the line of collimation produced is not exactly in that line, but is below it by an amount called the error from refraction, and thus the error arising from curvature is partly neutralised; and the correction to be subtracted for curvature and refraction usually is somewhat less than the correction for curvature alone.

The error produced by refraction varies very much with the state of the atmosphere, having been found to range from one half to one-tenth of the correction for curvature, and in some cases to vary even more. Its value cannot be expressed with certainty by any known formula; but when it becomes necessary to allow for it, it may be assumed to be on an average one-sixth of the correction for a curvature; so that the joint correction for curvature and refraction to be subtracted from the reading of the staff is—

$$\frac{5}{6} \times \frac{(\text{distance in feet})^2}{41{,}777{,}559} = \cdot 56\ (\text{distance in statute miles})^2.$$

Molesworth gives the following rule :—

D = distance in statute miles.

C = curvature in feet $= \frac{2}{3}$ D² approximately.

C — R = curvature less refraction $= \frac{4}{7}$ D² approximately.

From which the following table has been calculated :—

D.	C.	C — R.	D.	C.	C — R.	D.	C.	C — R.
1	·66	·57	6	24·00	20·57	12	96·00	82·00
2	2·67	2·29	7	32·67	28·00	14	130·00	112·00
3	6·00	5·14	8	42·67	36·57	16	170·00	146·00
4	10·67	9·14	9	54·00	46·30	18	216·00	185·00
5	16·67	14·29	10	66·67	57·51	20	266·7	228·6

Professor Rankine expresses an opinion that "the errors produced by curvature and refraction are neutralised when back and fore sights are taken to staves at equal or nearly equal distances from the level. At distances not exceeding ten chains they are so small that they may be neglected. The uncertainty of the curvature and refraction makes it advisable to avoid, in exact levelling, all sights at distances exceeding about a quarter of a mile."

Adjustments.—Before proceeding to level it is necessary to attend to the temporary adjustments, which require to be made each time the instrument is set up, as follows :—

1. To plant the legs of the instrument firmly in the ground, taking care that the parallel plates are made as horizontal as possible.

2. To level "the instrument," that is, to place the vertical axis truly vertical.

3. To adjust the telescope for the prevention of "parallax," that is, to bring the foci of the glasses to the cross-wires, look through the telescope, and shift the eye-piece in and out until the cross-wires are seen with perfect distinctness. Then direct the telescope to some well-defined distant object, and by means of the milled head screw, shift the inner tube in and out until the image of the object is seen sharp and clear, coinciding apparently with the cross-wire. This latter part of the adjustment must be made anew for each new object at a different distance from the preceding one. The nearer the object the further the inner tube must be drawn out.

A good test of the adjustment for parallax is to move the head from side to side while looking through the telescope. If the adjustment is perfect, the image of the object will seem steadily to coincide with the cross-wires; if imperfect, the image will seem to waver as the head is moved. If the image seems to shift to the opposite direction to the head, the inner tube must be drawn out further; if in the same direction, it must be drawn inwards.

Levelling is of two kinds, simple and compound. Simple levelling has only one line of collimation, whilst compound levelling entails constant changes of collimation, and hence the necessity for extreme accuracy in the work and care in the adjustment of the instrument. In the case of Fig. 216 the instru-

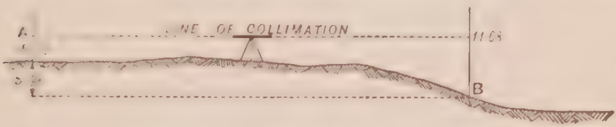


Fig. 216.

ment is placed equally between A and B, and the telescope being directed towards A, the line of collimation cuts the staff at 5·70 (this being the first reading is called the "back-sight"); * the telescope is then reversed, and the reading appears 11·68, consequently, by the invariable rule that if the intermediate or fore sights are greater than the back-sights they are "falls," and if less "rises." In the present case it is a fall of 5·98 feet from A to B. Here I would refer to a query which is frequently put by students: "How does the height of the instrument affect the result?" The height of the instrument has nothing whatever to do with the operation of levelling, and the only thing that will account for this fallacy is either that it is known to be requisite in levelling with a theodolite to have the distance of the axis of the telescope from the ground, and in the early days of levelling it was customary to note the height of the instrument. But I think I shall have no difficulty in showing that, as in the case of Fig. 216, the line of collimation being an imaginary line parallel with the horizon, the heights which are taken at A and B are in reality the depths of the surface of the ground at those points below the line of collimation, consequently it does not matter whether the instrument is 4 or 40 feet above the surface of the ground.

Compound Levelling consists of following the undulation of the

* In simple levelling, the first sight after the level has been planted and adjusted is always the "back-sight," and the very last sight before the instrument is removed is the "fore-sight;" all others are "intermediate."

ground, along a line of section, by means of varying lines of collimation according to the rise or fall of the ground.

Fig. 217 is a simple illustration of my meaning. The instrument is placed equidistant between A and B, and the reading of the staff at A is 4·10, whilst that at B is 10·15, showing a fall of 6·05. Next remove the level to *b* and establish a new line of collimation. Now what in the previous case was a fore-sight 10·15, the instrument again reads the same staff 5·30 as a back-sight, consequently the

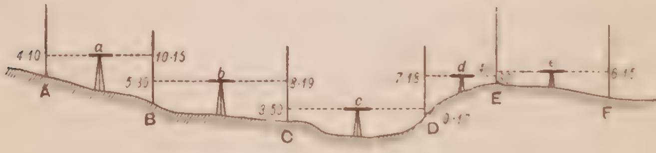


Fig. 217.

line of collimation is 4·85 lower than that from A to B. Now turn the telescope towards C for a fore-sight 8·19, and then move the instrument to *c*. Here again our line of collimation is lower, its exact depth being determined by reading off the staff at C a back-sight of 3·50, which gives a fall 4·69. Reverse the telescope for a fore-sight at D of 0·17, now move the level to *d* on higher ground, and we find that the line of collimation cuts the staff at D for a back sight at 7·18, or a rise of 7·01. At E the fore-sight is 0·30, whilst a back-sight from the level at *e* to E is only 0·40, showing the last line of collimation to be only 0·10 higher than the one from D to E, the staff at F showing a fore-sight of 6·15 shows a fall of 5·75 from E to F. We will now tabulate these results, and for the moment I shall only deal with two columns for the readings of back and fore sights, and the ordinary "rise" and "fall" columns.

Back Sight.	Fore Sight.	Rise.	Fall.
4·10			
5·30	10·15		6·05
3·50	8·19		2·89
7·18	0·17	3·33	
0·40	0·30	6·88	
	6·15		5·75
20·48	24·96	10·21	14·69
	20·48		10·21
	4·48		4·48

So that we see that by taking the less from the greater we get rises or falls, as follows: 10·15 being greater than 4·10 is a fall of 6·05, 8·19 being greater than 5·30 gives a fall of 2·89, whilst 0·17 being less than 3·50 we have a rise of 3·33; and similarly 0·30 being less than 7·18 we have a rise of 6·88, and 6·15 being again greater than the back-sight 0·40 we have a fall of 5·75. Now, to prove our calculations, if we take the sum of the rises from that of the falls we get the same result as deducting the sum of the back-sight from that of the fore-sight of 4·48, which shows that there is a total fall from A to F of 4·48 feet, regardless of the fact that the ground rises at D and E.

Now before I proceed to elaborate the subject of compound levelling, I think it advisable to deal with two primary questions, which may well be introduced at this point. I refer to datum and bench-marks.

Datum.—First, as to datum. It is an imaginary line parallel with the horizon, and equally with the lines of collimation. Its object is to simplify all calculations in levelling operations by referring all the observations to one fixed standard, which is fixed at some convenient depth below a well-known and clearly defined mark (called usually a bench-mark), and from this standard line all heights are relatively adjusted.

Ordnance Datum.—The ordnance datum of this country was determined by the ordnance authorities to be "the approximate mean water at Liverpool," and all the levels marked upon the ordnance maps are the "altitudes in feet above this datum, so that in the north of Scotland or in Wales, equally with Southampton or Yarmouth, all over the United Kingdom, whenever a figure preceded by a dot, thus ·33·6 or ·336·0, is upon a map, it shows in the one case 33 ft. and $\frac{6}{10}$th of a foot, and in the other 336 ft. above this datum respectively. It is not, however, usual or necessary to adopt the ordnance datum in ordinary levelling operations, but to assume some convenient depth below the lowest point of the section, the reason for which is obviously that all altitudes shall be above this datum, so that they will always be positive and never negative heights.

Now, as an illustration, referring to Fig. 217, seeing that by the level-book F is 4·48 ft. below A, we may safely assume our datum to be 20 ft. below A, and to elucidate the operation it is necessary here to explain that the calculated heights above datum are called *reduced levels*, and appear in another column next to the "fall" column. I repeat the level-book to show this.

Back Sight.	Fore Sight.	Rise.	Fall.	Reduced Levels	Remarks.
4·10				20 00	Below A
	10·15		6·05	13·95	At B
5·30					
	8·19		2·89	11·06	,, C
3·50					
	0·17	3·33		14·39	,, D
7·18					
	0·30	6·88		21·27	,, E
0·40					
	6·15		5·75	15·52	,, F
20·48	24·96	10·21	14·69	20·00	
	20·48		10·21	15·52	
	4·48		4·48	4·48	

Thus if upon a piece of paper a straight line be drawn, and at the points thereon A, B, C, D, E, and F, as in Fig. 218, vertical lines be drawn up, then if the reduced levels be plotted to the value given in the last column, you will have these points relative to a uniform datum of 20 ft. below A. It will be seen that so far as the instrument is concerned, the operation in the field is confined

Fig. 218.

exclusively to the back and fore sight columns, whilst the rise and fall and reduced level have reference to the office. I say this advisedly, because this book is for the information of the uninitiated, and I want to make it clear that, having accurately observed the readings of the staff at the back and fore sight stations, the identity of the instrument now ceases from the work. This is the real answer to the question so often put as to whether any notice is to be taken of the height of the instrument from the ground.

Bench Marks. I leave this portion of the question for the present, to consider the next important process, viz. that of bench-marks. It has been laid down as an invariable rule, that to secure a perfect system of levelling, some clearly defined and immovable point shall be established to serve as the basis of all operations. In other words, whether it is the top of a milestone, a corner of the top steps of some well-known building, a boundary

stone, the hinge-post of a gate, the trunk of a tree, or a mark cut on a wall, that such should represent the commencement of a series of levels, which shall be so accurately described and located as to enable the greatest stranger to easily determine its whereabouts.

Now, in selecting a bench-mark, if on a mile or a gate post, the highest point is always to be taken; or, in the case of a stone post, whose top may be uneven, by intention or wear, then select the extreme point, as shown in Fig. 219; and in the case of iron or round stone posts the apex, as in Fig. 220. Let me say one word re-

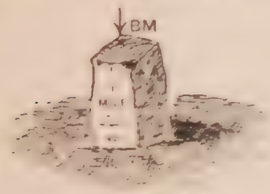


Fig. 219.

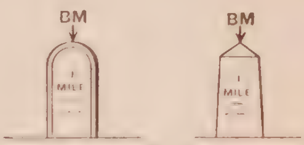


Fig. 220.

garding the habit of driving nails into the trunks of trees (Fig. 221). It is by no means a satisfactory one, and should be avoided except under most exceptional circumstances. It may be

Fig. 221.

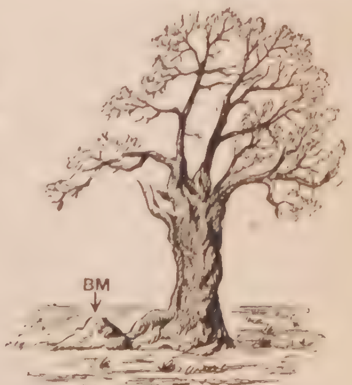


Fig. 222.

necessary to utilise a tree in close proximity to the work, in which case it is always advisable to cut a cross or crow's-foot on the root, as in Fig. 222. Again, it is usual to advise students to make bench-marks of gate-posts, the favourite expression being the "top

hook of the hanging post," as in Fig. 223. I can only say that this is a mistake, as the constant opening and shutting of the gate must loosen the hook and destroy the identity of the mark. The hanging post of gates, in the absence of any more suitable fixtures, may

Fig. 223.

Fig. 224.

do very well, but instead of being the hook, as in Fig. 223, it should be on the top of the post itself, as in Fig. 224. The door-steps of churches, chapels, public houses, farmhouses, &c., are frequently adopted for bench-marks, in which case it is always

Fig. 225.

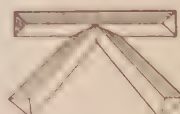


Fig. 226.

usual to take the top step (Fig. 225), and to be extremely careful to describe whether it is north, south, east, or west. Ordnance bench marks are invariably cut in the walls of buildings, public or private, or in stone or wooden mile or gate posts, and are in the form of a crow's-foot, similar to Fig. 226.

Position of Bench Marks.—Bench-marks need not necessarily be exactly on the line of section, nor is it essential that they should be at the commencement of the work. In starting to take levels the staff is held upon some convenient permanent mark, such as I have mentioned, as near to the work as possible. I have known cases where the only fixed point suitable for a bench-mark has been a considerable distance away, in which case it has been necessary to level expressly from this point to that of the com-

mencement of the section, even if it be a mile off or more. Upon the Sligo, Leitrim, and Northern Counties Railway we had only two bench-marks in 42½ miles' length, and each was some considerable distance from the commencement and termination of the rail way, and was on the top of iron mile-posts.

My advice is always to have frequent bench-marks, say one at every furlong, as they are invaluable at the time the section is taken or in after times for reference. If the operation of levelling takes longer than the one day, when leaving off always do so upon a bench-mark, from which you may safely resume your levelling at a subsequent date. In entering the position of a bench-mark in the level-book it needs to be described very minutely, somewhat thus: "B M on top of doorstep, N E corner of Coach and Horses P H" or "B M on top of sixth mile-post from Dover;" or "B M on top of hanging post of gate leading from main road to Cedar Farm."

Different Kinds of Levelling.—Levelling may be done in several ways: 1st, by taking observations of altitude at measured points upon a given line, which is called a section; 2nd, by taking observations of altitude at points along a road; 3rd, relative levels at points of an estate whose positions are fixed upon plan, and whose relative values to the datum are marked thereon.

First, as to a line of section. It is usual to set out a line either straight or curved, which shall comprehend a line of country of which it is necessary to determine the various features of undulation, commencing at a fixed point, as A. After having held the staff upon a bench-mark it is removed at A, which is the commencement of the section.

Level Book.—Before going into details, however, it is necessary that I should say a few words as to the level-book and the method of taking observations. As this book is destined to be a practical manual of field-work I make no apology for leaving out of consideration any other methods than those I am myself accustomed to adopt. The following is in my judgment the only form of level-book adapted to modern practice. It consists of seven columns on the left page and one column and a large space on the right page. The first three columns, viz. "back-sight," "intermediate," and "fore-sight," are exclusively for the observations with the instrument, and together with the seventh column on the left and the whole of the right page for "distance," "total distance," and remarks, these have reference only for field operations, whilst the fourth, fifth, and sixth columns, for "rise," "fall," and "reduced levels," need not necessarily be worked out in the field, but it is always as well to do so if time and circumstances permit.

LEVELS TAKEN IN WIMBLEDON PARK, JUNE 30TH, 1886.

Back Sight.	Inter-mediate.	Fore Sight.	Rise.	Fall.	Reduced Levels.	Distance.	Total Distance.	Remarks.
6·30					50·00			B. M on root of tree at A on plan.
	1·60		4·70		54·70			On peg at end of line 5.
	1·45		·15		54·85			On peg No, 2.
	0·55		·90		55·75			Centre of road.
		0·59		·04	55·71			Peg No. 3.
9·80					—			
	2 20		7·60		63·31	000		Commencement of section.
	4·30			2·10	61·21	100		At peg.
	5·90			1·60	59·61	150		”
	8·30			2·40	57·21	180		”
	10·00			1·70	55·51	200		”
	7·30		2·70		58·21	300		”
	4·90		2·40		60·61	400		”
	3·50		1·40		62·01	500		”
	·10		3·40		65·41	600		”
	10·50			10·40	55·01	700		”
		12·53		2·03	52·98	—		”
5·02					—	—		”
	4·70		·32		53·30	800		”
	8·60			3·90	49·40	900		”
	11·80			3·20	46·20	1000		”
	13·50			1·70	44·50	1100		”
		5·02	8·48		52·98	—		”
7·30					—	—		”
	7·40			·10	52·88	1200		End of section.
		10·27		2·87	50·01			B.M. on tree.
28·42		28·41	32·05	32 04				

Now referring to the level book just described, the instrument is planted in some convenient position to command the bench-mark on the root of a tree, marked A on plan. Direct the staff to be held thereon, and direct the telescope towards it. Carefully observe the reading where the cross wire cuts the staff—in this case it is 6·30. This is a back-sight. And here let me again impress upon the student that the *first sight* he takes after fixing the instrument is always a *back-sight*, and *the last* he takes before he removes the instrument is always a *fore-sight*, and all other sights are intermediate. Again, a back-sight signifies the commencement of a series of levels and fore-sight its termination. Now 6·30 is the first reading, therefore book it in the first column, and having entered it take another look to satisfy yourself that the reading is

correct.* Now there are three points at which it is desirable to have readings before moving the instrument—1·60, 1·45, and 0·55. These being connected with the same line of collimation will appear in the second or "intermediate" column, and for convenience of sight it is arranged that the chain-man should hold the staff at a point the reading of which is 0·59, which, being the last, will appear in the third or "fore sight" column, and we have now done with this line of collimation, and must proceed to establish another. But the staff must remain at the last point, only be careful that in turning the figures towards the new position of the level that it is exactly upon the same spot.† To better illustrate my meaning by reference to Fig. 227, the instrument is at A (for the first line of collimation), and B is the point deemed desirable for a change of collimation, the staff being held in some

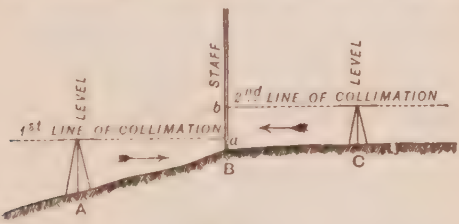


Fig. 227.

fixed point at B and the sight taken at *a*, the reading of which is 0·59. The second line of collimation is established by planting the level at C, and reading the staff still held at B, but cutting it at *b*, which reads 9·80. Now the 0·59 goes in the third column and 9·80 in the first, but whilst the readings are different the point B is just the same, the staff never having moved (except to turn its face towards C). The difference lies in the alteration of the lines of collimation, and it is most important to impress this fact, that the accuracy of the levels is entirely dependent upon the care with which the changes of collimation are made, so that if there is the slightest alteration in the point at B, where the sight at *a* and *b* is observed—in other words, if the staff in the process of turning has shifted only ever so slightly—the accuracy of the work is jeopardised, nay, destroyed. Let me further emphasise this. According to the reading of the staff at B the value of *a* is 0·59 when the staff is

* To carefully observe a reading and make a mental note thereof enables the leveller to accurately record it in the book; and looking again, after having booked it, will prove a corroboration of the observation.

† I always prefer, in cases of change, before establishing my fore-sight to select a stone peg or root of tree, in fact anything firm upon which the staff may be held. If in pasture land, instruct your man to carry a stone, and to well kick it into the ground before placing the staff upon it.

held on a stone (as *a*, Fig. 228). Now if the chain-man is not careful when he raises the staff to turn it towards the instrument, although he may place it back on the same stone, yet if from want of care instead of doing so at *a* he puts it upon a lower part of the stone, as *b*, then the differerence of the lines of collimation will be ½ in. out, and the identity of *a* and *b* at B, in Fig. 227, destroyed, for by this error of ½ in. they are not the self same spot.

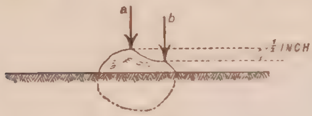


Fig. 228.

Foot Plates.—To obviate such an unfortunate contingency it is very desirable that the chain-man should carry slung on his arm an iron foot-plate, such as Fig. 229, or, for soft ground, a foot-peg, as Fig. 230.

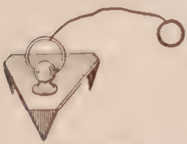


Fig. 229.

I think I have sufficiently explained the importance of these precautions, and now proceed with the second line of collimation, with 9·80 as the back-sight. By reference to the level-book it will be seen that the real commencement of the section is not until the first intermediate in the second line of collimation, viz. 2·20, and it is here that the seventh column is brought into use, and three

Fig. 230.

cyphers are booked to notify the zero of the horizontal measurement. At 1 chain occurs the second intermediate 4·30, and following at 150, 180, 200, 300, 400, 500, 600, and 700 links are eight intermediate sights, 5·90, 8·30, 10·00, 7·30, 4·90, 3·50, 0·10, and 10·50, and for the convenience of changing we now make a fore sight at 12·53, thus ending the second line of collimation. The third line of collimation begins with a back-sight of 5·02, has four intermediates of 4·70, 8·60, 11·80, 13·50 at 800, 900, 1,000, and 1,100 links, and is terminated by a fore sight of 5·02, which is by no means of uncommon occurrence. The third line of collimation begins with a back-sight of 7·30, has an intermediate of 7·40, and terminates on the same bench mark from which we started, of 10·27. I have given this illustration, taken from actual practice over a portion of a section of a railway, which by being for the first 1,200 links round a very sharp curve, gave the section the form in

which it appears in Fig. 231, and also enabled us to tie upon our original bench-mark.

Keeping the Level Book.—I now wish to speak of the method of keeping the level-book, and shall take Example No. 1 for illustration. On p. 193 I have explained that if the "intermediate or fore sights are greater than the back-sight it is a fall, and if less a rise," and thus in the present case we shall have no difficulty in making up our book as follows. Working diagonally downwards from left to right, 1·60 being less than 6·30, is a rise of 4·70; 1·45 being less than 1·60 is also a rise; 0·55 being less than 1·45 is a rise; but 0·59 being greater than 0·55 is a fall of 0·04. We have now completely done with the first series; and although the back-sight 9·80 and the fore-sight 0·59 are identical, yet I prefer to start a fresh line, as a better illustration that each series is independent of the other. Thus 9·80 back-sight being greater than 2·20 (intermediate) is a rise, but 2·20 being less than 4·30 shows a fall of 2·10, and 4·30 less than 5·90 a fall of 1·60, and so on until 10·00 being greater than 7·30 we have a rise of 2·70, 2·40, 1·40, 3·40, a fall of 10·40, and finally the fore-sight 12·53 being greater than the last intermediate 10·50 shows a fall of 2·03. Now a new line of collimation, with a back-sight of 5·02, we have a rise of 0·32, the three intermediates showing falls of 3·90, 3·20, 1·70 respectively, whilst the fore sight gives a rise of 8·48, and the fourth and last line of collimation has a fall from the back sight of 0·10, and also on to the B.M. a fall of 2·87.

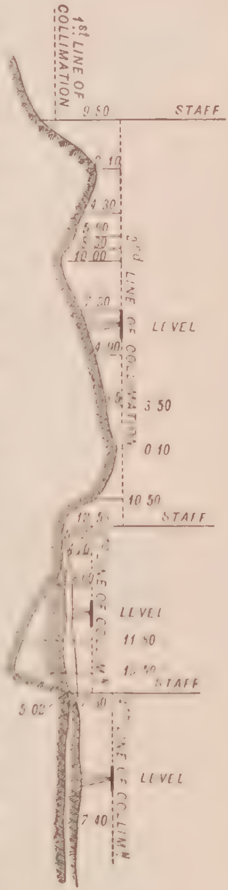


Fig. 231.

Making up Level Book.—It is here necessary to explain how to make up the level-book. We have seen that, commencing with a back-sight of 6·30 on the bench-mark, we terminate upon the same point with a fore-sight of 10·27, and that we have four back sights of 6·30, 9·80, 5·02, and 7·30, giving a total of 28·42 ft., and also four fore-sights of 0·59, 12·53, 5·02, and 10·27, in all 28·41 ft. Thus the back-

sight being greater by 0·01 than the fore-sight shows a discrepancy of $\frac{1}{100}$th of a foot, or $\frac{1}{8}$th of an inch. In so short a distance this should not occur, as 1 in. in four miles is considered the allowance for errors. I have purposely shown it thus to illustrate my meaning. Now if we have correctly reduced the intermediate and fore sight from the back-sight, the rises and falls if added together should give the same difference as that existing between the back and fore sights, or 32·05 rise — 32·04 fall = 0·01. Now on p. 193 I have spoken about datum, and in the present case I have assumed a datum of 50 ft. below the bench-mark. This 50 ft. appears in the sixth column, opposite the 6·30 in the first, and it will be necessary to carry forward the system of reduced levels by adding or deducting the consecutive rises or falls as follows: 50·00 + 4·70 = 54·70, 54·70 + 0·15 = 54·85, 54·85 + 90 = 55·75, 55·75 — 0·04 = 55·71. This last being a fall must be deducted. There is no reduced level opposite 9·80 in the back-sight column, as being identical with 0·59 in the fore-sight column; its value is just the same * above datum of 55·71, and to save confusion I simply draw a dash across the space. Then to 55·71 must be added 7·60 = 63·31; from 63·31 — 2·10 = 61·21; from 61·2i — 1·60 = 59·61; 59·61 — 2·40 = 57·21; 57·21 -- 1·70 = 55·51; 55·51 + 2·70 = 58·21, and so on until the last fall of 2·87, opposite the last fore-sight 10·27, gives a result of 50·01, from which should be taken the height above datum, viz. 50·00 = 0·01, or $\frac{1}{100}$th of a foot. Having thus obtained all our reduced levels, we now proceed to plot our section, of which I shall have something to say later on. But I want to explain how to avoid any complications or inaccuracies with the level-book in cases where there are a large number of intermediate sights, so much so as to go over on to the next page. The following is a very simple illustration.

* Some surveyors prefer to place their back and fore sights upon the same line, as in example A; but I prefer to devote a separate line to each observation, as in example B, which shows more clearly the various lines of collimation.

A

B. S.	Inter	F. S.
9·80		0·59

B

B. S.	Inter.	F. S.
		0·59
9·80		

TWO METHODS OF KEEPING THE LEVEL BOOK.

(USUAL METHOD.)

Page No. 1.			Page No. 2.		
Back Sight.	Inter-mediate.	Fore Sight.	Back Sight.	Inter-mediate.	Fore Sight.
			16·10		·59
6·30				3·50	
	1·60			·10	
	1·45			10·50	
	·55		5·02		12·53
9·80		·59		4·70	
	2·20			8·60	
	4·30			11·80	
	5·90			13·50	
	8 30		7·30		5·02
	10·00			7·40	
	7·30				10·27
	4·90				
16·10		·59	28·42		28·41

(AUTHOR'S METHOD.)*

Page No. 1.			Page No. 2.		
Back Sight.	Inter-mediate.	Fore Sight.	Back Sight.	Inter-mediate.	Fore Sight.
			16·10		5·49
6·30			4·90		
	1·60			3·50	
	1·45			·10	
	0·55	·59		10·50	
9·80					12·53
	2·20		5·02		
	4·30			4·70	
	5·90			8·60	
	8·30			11·80	
	10·00			13·50	
	7·30				5·02
		4·90	7·30		
				7·40	
					10·27
16·10		5·49	33·32		33·31

* See Note, p. 202

hook of the hanging post," as in Fig. 223. I can only say that this is a mistake, as the constant opening and shutting of the gate must loosen the hook and destroy the identity of the mark. The hanging post of gates, in the absence of any more suitable fixtures, may

Fig. 223.

Fig. 224.

do very well, but instead of being the hook, as in Fig. 223, it should be on the top of the post itself, as in Fig. 224. The door-steps of churches, chapels, public houses, farmhouses, &c., are frequently adopted for bench-marks, in which case it is always

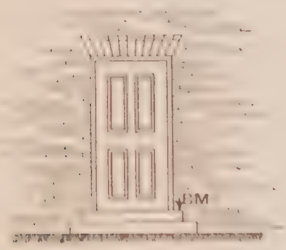


Fig. 225.

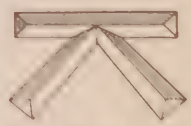


Fig. 226.

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holder holds it on the surface of the ground, and when directed moves along the chain if required or to the end. He should be well acquainted with reading the divisions on the chain, as it is sometimes necessary to book the distances from a point away, in which case you must trust to your chain-man, but *not* if you can possibly avoid it.

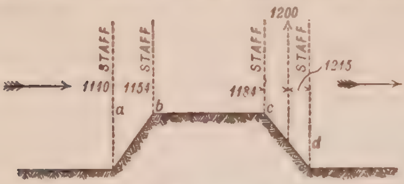


Fig. 236.

Now across open ground there is little need for taking sights oftener than at the end of each chain, unless the ground be very undulating. In crossing a bank similar to that in Fig. 236, it is necessary to take the tops and bottoms—thus, 1140*a*, 1154*b*, the near bottom and top of slope, 1184*c* the foretop; whilst 1200 comes part of the way down the slope, the bottom of which *d* is 1215, but in a case of this kind it is not absolutely necessary to take a level at 1200, being so near to 1215.

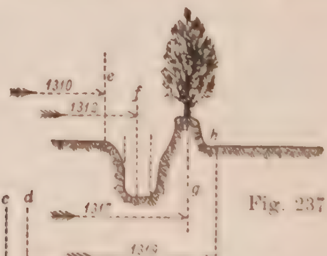


Fig. 237.

Fig. 238.

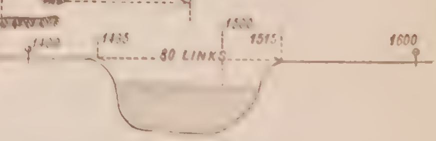


Fig. 239.

In the case of Fig. 237, in crossing a ditch and fence levels are required at *e*, *f*, *g*, and *h*, but distances must be taken at those points such as 1310, 1312, 1317, and 1319, and it is as well to make a sketch in the level-book similar to Fig. 237. In crossing a river, whose width admits of both banks being observed from the same station, it is usual to take the edge of each bank and the impingement of the water on the shore, as *a*, *b*, *c*, *d* in Fig. 238, and if sufficiently shallow to allow the staff to be read with the bottom upon the bed so much the better, if not the depth of the surface of the water above the

bed must be ascertained by sounding either with the levelling staff, or, if not long enough, with a line and lead.

Measuring across Streams.—If the river be too wide to measure with a chain, resort will have to be had to one or other of the methods of calculating the width described in Chapter **IV.** It sometimes happens, as in Fig. 239, that the end of a chain comes near to the edge of a river, but whose width is too great to admit of a chain-peg being on the other side; in such a case it is unnecessary to resort to calculation, if the exact width is taken with the chain, supposing it to be not wider than 100 links, by care it is possible to connect and to continue the chainings. In this case the near edge of the river is 1,435, and the width to the opposite edge is 80 links, thus 1435 + 80 = 1515, and if 15 links is held at that point, then the end of the chain will be 200 links from the last arrow at 1400. In the case of a wide river, of say 3 or 4 chains' width, it is desirable to establish a bench-mark and send a man across with a staff and instruct him to hold the staff upon a bench-mark on the other side, then take a long-distance sight across and allow for curvature and refraction. This only as a test of the subsequent operation of levelling round by possibly a circuitous

Fig. 240.

route as shown in Fig. 240, when it may be necessary to sight for upwards of 1½ miles round by a bridge or across some convenient ford, in which case, having levelled from A to B, it will be absolutely imperative to check back from B to A before continuing the section. In taking the level of water of a tidal river it is necessary to ascertain the level of high and low water.

Providing for Curvature, &c.—It will have been noticed that, in speaking about curvature and refraction, I said it was seldom

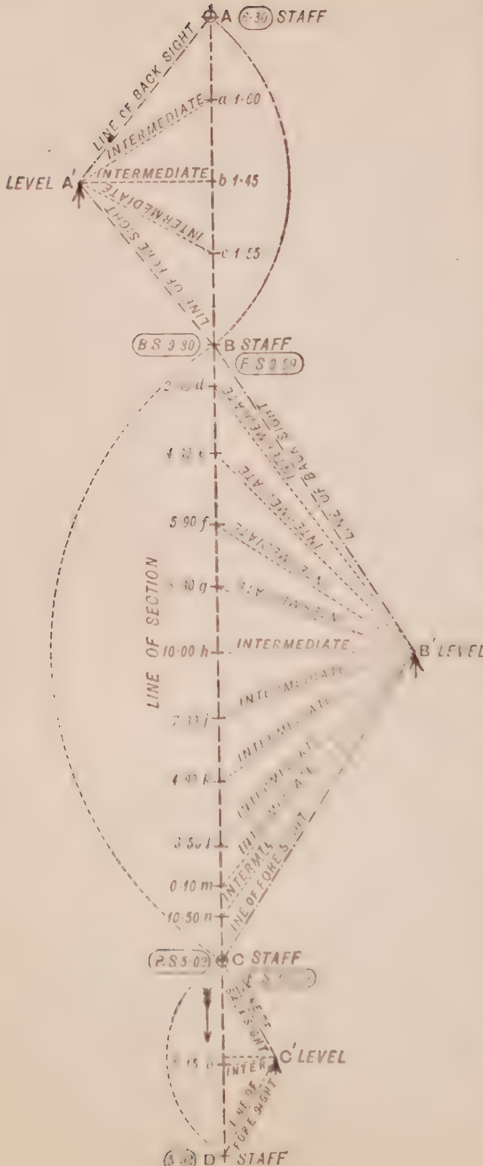


Fig. 241.

considered in modern practice, as by equalising the distance between the staff at each end and the instrument the necessity for making the allowance would be obviated. If only back and fore sights are required it will not be difficult to arrange for the equidistance of the staff, but it does not necessarily follow that the instrument must be exactly in line with the staves. Always select some eligible position upon which to plant your level, so as to command as large a range of your work as possible consistent with the necessity to have the back and fore sights equidistant.

In Fig. 241 I give a simple illustration, which really deals with the whole question, however complicated. In the line of section from A to D it is assumed that we commence at A with the staff reading 6·30, from the instrument being at A′, the staff is then held at a (1·60), at b (1·45). and c (1·55), all three intermedi-

ates, and finally at B for a fore sight, the same distance (or thereabouts) as from A. Now by keeping A and B the same distance from A′ we have fulfilled the condition required by curvature and refraction, and if the instrument is in perfect adjustment the depths of the intermediates *a*, *b*, *c*, below the line of collimation A B, although of different radii to A and B, yet for all practical purposes will be sufficiently accurate. This will be possibly better understood by reference to Fig. 242. Here let me say that, whilst it is absolutely essential that the back and fore sights should be most accurately observed, because the difference of their sum will be the actual rise or fall from the commencement to the termination, yet for all practical purposes it is not necessary (except in the case of the level of water, existing railways, or road crossings) to read nearer than tenths. Thus 1·43 would be booked 1·40, and 1·47 would appear as 1·50. By so doing a great deal of unnecessary labour and complication in making up the book is avoided, and seeing that even with the largest scale in practice it is impossible to plot less than $\frac{1}{100}$th of a foot, it is a needless waste of time to observe so minutely in the field.

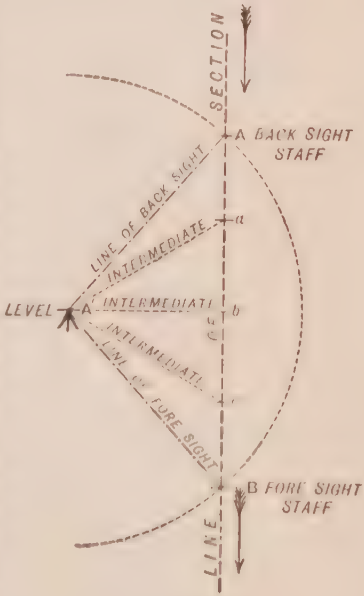


Fig. 242.

Passing back to the consideration of Fig. 241, having observed the fore sight at B (0·59), and previously taken care that the staff is held upon some firm place, the face thereof being now turned towards B′, to which point the instrument has been transplanted, and when adjusted the reading of the back sight at B is 9·80, and now follow the various points along the line, *d* (2·30), *e* (4·30), *f* (5·90), *g* (8·30), *h* (10·00), *j* (7·30), *k* (4·90), *l* (5·30), *m* (0·10), and *n* (10·50), all intermediates, whilst C (12·53) is the fore sight. The same principle as previously explained equally applies, and so on *ad infinitum*, showing at the finish of the section—

Back sight.	Fore sight.
6·30	0·59
9·80	12·53
5·02	5·02
21·12	18·14
18·14	
2·98 rise from A to D.	

This is only a very simple illustration, but it may be adopted either for a great length of section or for a few chains.

Instructions to Staff-holder.—It is desirable that the surveyor should direct the staff-holder as to the points at which it is necessary to take "readings," especially for back and fore sights, and unless he has some trustworthy person to read the distances on the chain-line he should ascertain the longitudinal measurements himself; certainly he must personally superintend the establishment of bench-marks, and see that the staff is not only held on the highest point, but that it is the same place which is described in the "remarks" column.

Plenty of Information.—Another point is that the remarks should be in as much detail as possible, accompanied by neat and graphic sketches of any important features met with in the section, especially with regard to the bench-marks. A sight should certainly be taken at the end of every chain except under exceptional circumstances. It may be well here to explain, that it is not by any means necessary that there should be any longitudinal measurements at either a back or a fore sight, but if it be found convenient to change at a point on the line of section which is to be determined by measurement, then the distance will appear opposite the foresight and opposite the next back sight (which represents the same spot). There will be no distance, but for facility in after work a dash should be drawn across the column. Thus, referring for illustration to Fig. 241, if at B it had been intended to have another intermediate, but the surveyor found that the rise of the ground would hardly justify his changing further, instead of entering 0·59 as an intermediate, he would book it as a fore sight, and put the distance upon the chain-line opposite, as in Fig. 243, and having moved the level to B′ in sighting the staff held at the same place (viz. B) would read and enter in the first column the back sight 9·80, so that at 1·60 the distance was 1 chain (100 links), at 1·45 = 200, at 0·55 = 300, at F S 0·59 = 400, at B S 9·80 = 000, at 2·30 = 430 links, and so on. I should explain that in Fig. 241 the back and fore sights at A, B, C, and D are, for particular illustration of a system, shown upon the line of section, but there is no absolute rule for this, as provided the prin-

ciple of having the back and fore sights equidistant, they may be at any point right or left of the line. Then again, I have been frequently asked if the first back sight is the commencement of the section? I say, no. The first back sight must necessarily be upon a bench-mark, in as near proximity to the commencement of the section as possible; but as a general rule the zero of the chainage is an intermediate; and the same applies to the last fore sight, which may be some distance from the termination of the section, involving a number of back and fore sights before the bench-mark is reached. And when this has been done, then the difference between the sum of the back sights and fore sights will represent (or should do) the difference between the levels of the first and last bench-mark.

Back Sight.	Intermediate	Fore Sight.	Distance
6·30			000
	1·60		100
	1·45		200
	1·55		300
		0·59	400
9·80			—
	2·30		430
	4·30		500

and so on.

Fig. 243.

Again, as the intermediate sights are the depths below the varying lines of collimation (which only are regulated by the back and fore sights), and so long as they have been accurately observed, they are disregarded in making up the field-work, and are only affected in the rise and fall columns, as connected with the reduced levels. But let it be said that the accuracy of the section so far as its details are concerned is entirely dependent upon the care with which the intermediates are observed, especially in reading long distances, as a IX. may be easily taken for XI., which involves an error at this particular point on the section of two feet, but does not in any way affect the whole section. Patience and care will obviate such an unpardonable error.

Taking the Level of Water.—In taking the level of the surface of water it is best to so place a stone on the fore-shore that it is only just covered with a film of water, and then hold the staff upon the stone. This applies only to standing water; but for a tidal stream the exact time of the observation should be chronicled, and, from a nautical almanack or by other means, the exact position of high and low water may then be determined.

Levelling with Theodolite.—Except under circumstances which are unavoidable, the use of the theodolite for levelling purposes should be confined to ascertaining inaccessible points or for the heights of mountain sides, for which the ordinary operations are inadmissible. In Austria, when working against time, I was compelled to use the theodolite for taking cross-sections of a ravine, the

results of which were afterwards at leisure fairly confirmed by the level.

A point at the bottom of the slope must be accurately determined by the ordinary means, and above this the height of the axis of the theodolite must be carefully ascertained. Thus, as in Fig. 244,

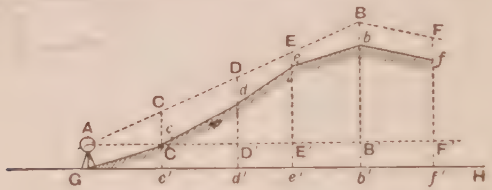


Fig. 244.

the dotted line A B will represent the hypotenuse of the right-angled triangle B A B', and with the distance G b' it is possible to calculate the height B B', and deducting from that B b, and adding to this result the height A G or B' b', we get the height b b. A simple illustration of this will be found in Fig. 245. Here the angle C A C'

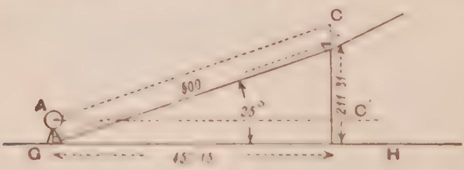


Fig. 245.

= 25°, and the distance G C measured along the slope is 500 feet. Then

$$c\,c' = A\,c \times \sin. 25^\circ = 500 \times \cdot 42262 = 211\cdot 31 \text{ feet};$$

but A is 5 feet above G, and c is the same height from c, and so is c' H = 5 feet. Therefore c H = 211·31. And A C or G H is found as follows:—

$$G\,H = A\,c \text{ (or } G\,c) \times \sin. 65^\circ = 500 \times \cdot 90631 = 453\cdot 15 \text{ ft.}^*$$

And the heights c c', d d', e e', and b b, and the distances G c', G d', G e', and G b' (Fig. 244) may be found in a similar manner, by treating the cases as right-angled triangles, C A C', D A D', E A E', and B A B', and plotting the calculated heights and distances from the datum line G H. In the case of going down hill you reverse the triangle, making B A the base and F B A the angle.

* In these calculations we take the sine and cosine of the complement of 25° or those of 65°.

Levelling with Aneroid.—The aneroid barometer has been fully described in Chapter III., and it is necessary only to explain its manipulation in the field. The larger the size, the more satisfactory the observations. The surveyor should provide himself with an accurate plan or map of the district through which he proposes to take the levels, and at the points of observation he should mark with a small dot, and place letters as A, B, C, &c, so that he may identify their relative positions from his note-book in which he records the readings. The temperature at starting should be noted, and the index or zero of the movable scale "should be set to where the hand of the instrument points." "On ascending a mountain the hand travels backward, and as each division represents 100 ft. (on the movable scale), an approximate indication of the ascent is thus readily obtained." The aneroid should be held perfectly horizontal and gently tapped during an observation. "Subtract the reading at the lower station from that at the upper station; the difference is the height in feet."

Cross Sections. — Cross-sections in their general acceptance mean a line of levels taken at right angles to the longitudinal section at every chain, or oftener if necessary. Their length is regulated by circumstances; for railways from 1 to 5 chains on each side, at points right and left at all changes of contour. They are set out either with a cross-staff or preferably an optical square. The most satisfactory and accurate method is to treat the sections at each chain as consecutive members—0, 1, 2, 3, 4, &c., starting at the commencement of the longitudinal section and looking in direction of its termination to treat all observations, either of height or distance, as being right or left of the centre line (or line of section), as in Fig. 246, and having set out three

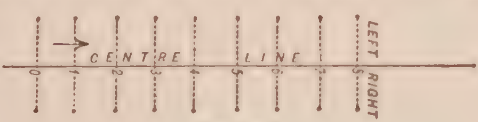


Fig. 246.

sight lines, commence to measure from the centre, right, and left in each separate case, noting any irregularity in the surface of the ground. These measurements should be personally made by the surveyor, who should be provided with a quantity of pieces of white paper (about $1\frac{1}{2}$ in. square), upon which he should write the number of the cross-section, the measurement in feet (all cross-sections should be measured in feet), and after these particulars have been carefully written upon a piece of paper, it should be placed in a slit of some twigs of trees, pointed at the other end, and stuck in the ground at the point observed. Thus, as in

Fig. 247, it will be observed that the cross-section is at $\overset{\text{M. CH.}}{0 \cdot 01}$ (no miles, 1 chain), and on the right hand side there are five points, *a*, *b*, *c*, *d*, *e*, of 10 ft., 25 ft., 39 ft., 58 ft., and 66 ft. from the centre, whilst on the left there are also five points, *f*, *g*, *h*, *j*, *k*, of

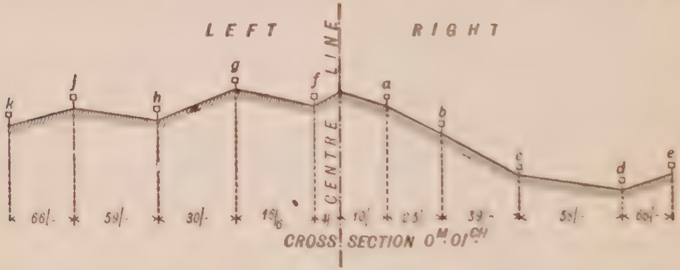


Fig. 247.

4 ft., 16 ft. 6 ins., 30 ft., 59 ft., and 66 ft. respectively. Take the point *b* on the right and *g* on the left, they would be marked on the paper, as in Figs. 248 and 249, No. 1 section, 25 ft. right and 16 ft. 6 in. left. The chief advantages claimed by this process is, that not only does the surveyor personally superintend these preliminary operations, but after a series of eight or a dozen cross sections have been set out and measured all the higher points

Fig. 248.

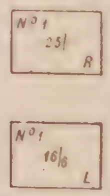


Fig. 249.

of the series may be taken from one point, so that the change of instrument is minimised. The staff-holder, who should be properly instructed as to his duties, proceeds to each of the points, and holding the staff thereat, he picks up the ticket, and at a signal from the surveyor he reads out in a clear, loud voice, "Cross-section number one, fifteen feet 6 inches left," the surveyor booking this repeats it, and if correct the ticket should be destroyed, so as not to be taken again.

In conclusion, I recommend the surveyor to make his assistants thoroughly understand their duties and his requirements, and, by a code of signals mutually understood, a great deal of satisfactory work may be accomplished in almost dumb show.

CHAPTER X.

CONTOURING.

CONTOURING is the art of delineating upon a plan a series of lines which represent certain altitudes parallel with the horizon, or, in other words, "lines of intersection of a hill by a horizontal plane." The simplest illustration is the high and low water marks along the sea shore, where the fringe of seaweed marks the extreme boundary of high water, and its zig-zag outline is due to the water finding out the inequalities of the level of the shore, so that whatever form this fringe may take, all round the coast of this "sea-girt island" will be found a line representing one uniform level parallel with the horizon.

Another and very primitive illustration: if varying quantities of different coloured liquids, commencing with the lightest colours in the largest quantities, were poured into some basin-shaped vessel whose sides would absorb some of the colours, so as to leave the mark of its highest level, and smaller quantities of colour of gradnating darkness were successively poured in and emptied out, the defined lines made by those different colours would represent concentric circles on the sides of the basin, whose distance apart would be governed by the varying quantities of the different coloured liquids, and these lines would be the contours of the sides of the vessel.

Vertical Intervals and Horizontal Equivalents.—It is the province of the modern surveyor to practically show upon his plans these lines of contour. The known difference of height thereof are called the *vertical intervals*, and their distance apart upon the survey are termed the *horizontal equivalents*, as will be seen by Fig. 250. In Figs. 251 and 252 we have a simple illustration of contour lines upon the truncated cone (Fig. 251) at points A, B, C, D, E, F, G, H, which in plan are represented by the concentric circles in Fig. 252, so that in the former case the relative height of B over A, C over B, &c., represent the vertical intervals, whilst in Fig. 252 the distance of B from A, C from B, &c., are the horizontal equivalents.

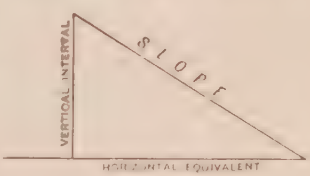


Fig. 250.

In Figs. 253 and 254 we have examples of the form contour lines

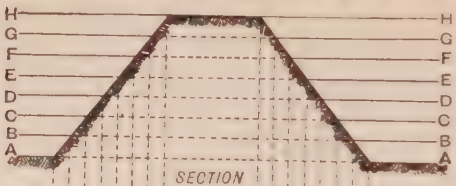


Fig. 251

Fig. 252.

will show on plan whose planes are projected from a section of

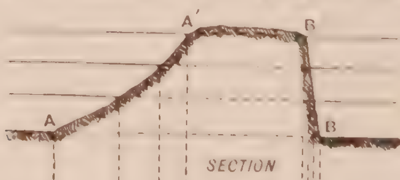


Fig. 253.

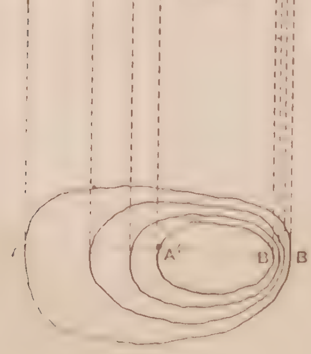


Fig. 254.

irregularity. The contours will occur in smaller horizontal dis-

tance, in proportion to the steepness of the ground. The contour lines in Fig. 253, besides giving the relative altitudes, explain the form and flexure of every slope, thus A A′ and B B′ (Fig. 253) show the exact concavity and convexity of the slopes A A′, B B′ in Fig. 254.

Now these vertical intervals are to be determined by two methods; 1st by angular observations, 2nd by means of levelling.

Hypotenusal Allowance.—We will briefly consider the first system. It has been shown in the chapter on chain surveying, that in chaining up the slope of a hill it is necessary to make an allowance for hypotenusal measurements by observing the angle which the slope makes with the horizon; and in the inverse ratio, by the same process, it is possible to calculate the difference of level between points on a hillside by finding the natural sine of the angle of slope. To take a simple illustration, suppose, as in Fig. 255, we have a slope forming an angle of 10 deg. with the horizon, and it is desired to establish at C a point whose height above B shall be 25 ft. By measuring 143·96 ft. from A along the slope we shall at C get this point, whose horizontal equivalent is 141·78 ft. In Fig. 256 we have an instance of the slope of a hill taking three different forms of flexure, as at C, D, and E, where the slopes are relatively 10°, 35°, and 65° with the horizon. We have seen that, requiring a vertical interval of 25 ft. between A and C with the first angle of 10°, the horizontal equivalent will be 141·78 ft.; for the second angle of 35° with the same altitude the horizontal equivalent will be 35·70 ft., whilst the hypotenusal measurement

Fig. 255.

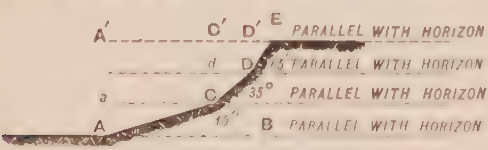


Fig. 256.

from C to D will be 43·58 ft.; and in the case of the third slope of 65°, with a vertical interval also of 25 ft., the horizontal equivalent D E will be 11·65 ft., and the distance along the slope from D to E 27·56.

It may be well that I should explain how the foregoing results have been obtained. The natural cotangent of the angle of slope in the case of 10° is 5·6713, and this multiplied by the vertical interval 25 ft. gives a result of 141·78 as the horizontal equivalent. Next, if the natural secant of 10° or 1·01543 be now multiplied

by 141·78 ft., it gives 143·96 ft. as the length of the slope from A to C.

A simple but not theoretically correct method, sufficient for practical purposes, will be found as follows:—

The horizontal equivalent or cotangent of 1° = 57·29; multiply this by 25 (or the vertical interval), and you obtain 1432·25 ft. for the horizontal equivalent.

Then for the angle of slope of 2 we must divide 1,432·25 by
2 = 716·125 ft.

And further

$$\text{At } 3 \ \frac{1,432 \cdot 25}{3} = 477 \cdot 417 \text{ ft.}$$

$$\text{At } 4 \ \frac{1,432 \cdot 25}{4} = 358 \cdot 062 \text{ ft.,}$$

and so on, for the better illustration of which I have compiled the following:—

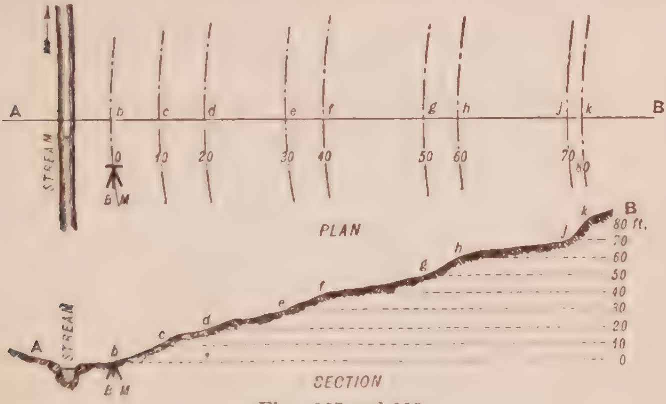
TABLE OF HORIZONTAL EQUIVALENTS OF VARYING ANGLES OF SLOPE FOR A VERTICAL INTERVAL OF 25 FEET.

		Feet.			Feet.			Feet.
1°	=	1432·25	11°	=	130·20	21°	=	68·20
2°	=	716·12	12°	=	119·35	22°	=	65·10
3°	=	477·42	13°	=	110·17	23°	=	62·21
4°	=	258·06	14°	=	102·30	24°	=	59·67
5°	=	286·45	15°	=	95·48	25°	=	57·29
6°	=	238·71	16°	=	89·51	26°	=	55·08
7°	=	204·60	17°	=	84·36	27°	=	53·04
8°	=	179·03	18°	=	79·01	28°	=	51·15
9°	=	158·02	19°	=	75·38	29°	=	49·42
10°	=	143·22	20°	=	71·61	30°	=	47·74

For military or other approximate purposes such a system is admissible, and 25 ft. vertical intervals are quite sufficiently near for the purpose.

Figs. 257 and 258 will best illustrate the application of the preceding examples. Fig. 258 represents a section taken from A to B. The points *b*, *c*, *d*, *e*, *f*, *g*, *h*, *j*, and *k* are those where the dotted lines or intervals of 10 ft. vertically intersect the irregularities of the ground. If these points be projected upwards, as in Fig. 257, they will show on plan the relative horizontal equivalents, and will form one of a series of lines which are used to delineate on plan the figures formed by these horizontal planes, as is further illustrated in Fig. 259, where the lines of section A B and C D show the various directions and distances apart of the contour lines *a b*, *c d*, *e f*, *g h*, and *j k*. The total vertical interval of *a b* and *j k* is 100 ft., and the intermediate dotted lines show the relative positions of the con-

tours at 25, 50, 75, and 100 ft. respectively. Similarly, in Figs. 260 and 261, it will be seen that the section line A to B, after cutting the points at *a*, *b*, *c*, *d*, and *e* at *d*, 25, 50, 75, and 100 ft. respec-



Figs. 257 and 258.

tively, descends to *d'* and *e'*, 75 and 50 ft., and then ascends to *d*, *e*, *f*, and *g*, 75, 100, 125, and 150 ft. above *a*. Thus it is

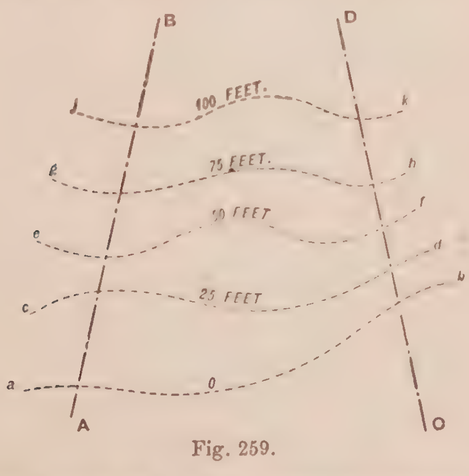


Fig. 259.

possible from a map which has been properly contoured to obtain a section such as that in Figs. 258 and 261.

In Chapter II. I have explained, under the head of measuring a long sloping ground, the *modus operandi* of taking the angle of

slope with a clinometer, and Figs. 31 and 32 will illustrate the methods to be adopted; and I do not think it is necessary to recapitulate these facts, especially as I do not consider that contouring by angles is at all reliable for practical purposes.

Contouring, to be of any real value, can only be done by levelling, and consequently it is a more elaborate and lengthy process, and is only justified in exceptional cases.

In Fig. 262 it will be seen that we have described a road passing through a valley from A to B, across some flat, marshy ground,

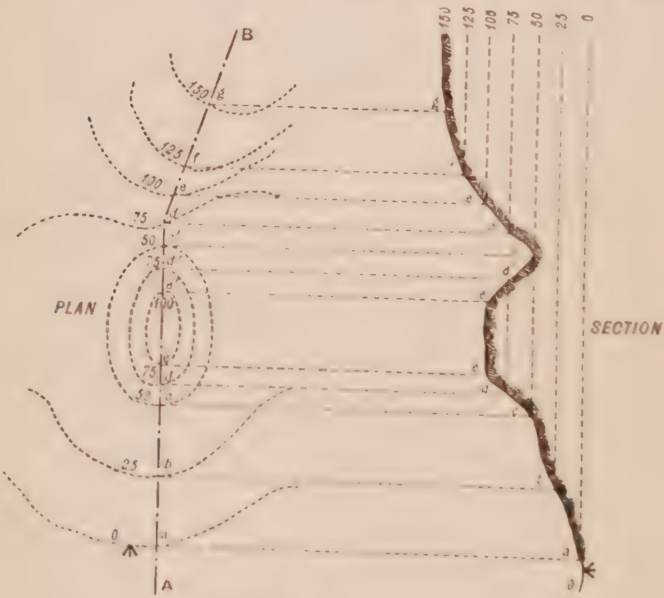


Fig. 260.

Fig. 261.

whilst from B to C it ascends the side of a hill. For the purpose of illustration I have assumed that it will be necessary to make a survey of so much as is comprehended in the figure. Now a line from D to E shows a descent from D of 250 feet to *d*, and after crossing the level ground to *e*, an ascent to E of 300 feet. This is, as it were, an index to the whole procedure; and after having been roughly levelled with an aneroid or by other means, to give an idea of the varying altitudes, we are now in a position to commence work.

It is necessary that I should here explain the elementary process of contouring by levelling. Commencing at the lowest position in

the survey, it is necessary to determine what should be the relative level of this point: I mean, should it have reference to Ordnance or other datum, or should it be considered as a "zero" point.

It will be seen in Fig. 263 that from A to B is a road with a junction of another from C to D. By the levels along the road it will

Fig. 262.

be seen that above Ordnance datum they are 34, 36, 37, and 35 ft., and the ground rises on either side. Now if we run a line such as E F for the purpose of establishing our contours, it will be necessary for us to determine whether we shall connect our contours with Ordnance datum—and with 10-feet vertical intervals

there would appear, as on the left side of E F, 40, 50, 60, 70, 80, and 90 feet respectively—or whether we should disregard any other datum, and assume that the point G to be zero, and consequently *b*, *c*, *d*, *e*, *f*, and *g* to be 10, 20, 30, 40, 50, and 60 feet above this point. Having once established upon what basis it is intended to proceed, the principles of action are exactly the same. We will for simplicity determine that we commence *de novo* at G, and that all altitudes above this will follow from zero. Now it is necessary to establish at this point some permanent bench-mark, such as a

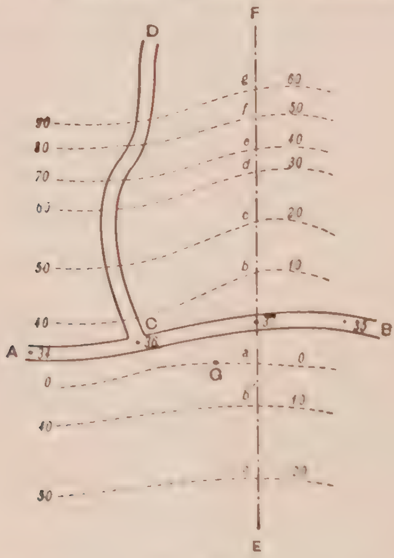


Fig. 263.

stout peg say 2½ inches square, driven level with the surface of the ground at this point. From this in a straight line towards F a series of contour bench marks, consisting of pegs driven in at *b*, *c*, *d*, *e*, *f*, and *g*, representing altitudes of 10, 20, 30, 40, 50, and 60 feet, should be established. Referring to Fig. 262, it will be seen that the contour-lines take very meandering routes, and the closer they are to each other the steeper the ground, and *vice versa*. Now it is necessary that I should explain the reason of the lines F G, H J, and K L in Fig. 262, to illustrate which I must refer to Fig. 263. It is usual to run lines of bench-marks at right angles to lines which are tangential with the foot of the slope. As C D is to A B, *c d* to *a b*, and *c′ d′* to *a′ b′*, Fig. 264, and F G, H J, and K L in Fig. 262, so that *d*, K′, H′, F′, and *c* are all exactly the same level, or zero. These points have to be determined by very accurate level-

ling: and pegs should be put in level with the surface of the ground, as A, Fig. 265, and beside it should be drawn another peg

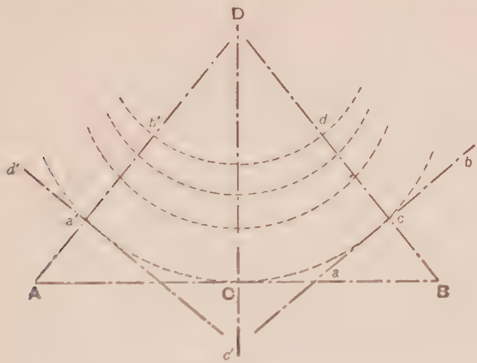


Fig 264.

to mark its position, which may be two or three inches out of the ground. This peg should be cut as explained in Chapter II., and the particulars of its height marked upon it. We now proceed to establish the other bench-marks, as are shown in Fig. 266. In this case we assume that the vertical intervals shall be 10 feet, so that F is 50 feet above A. I have elected to give in Fig. 267 a rough illustration of the method by which these lines of bench-marks are determined. Suppose the level-staff be held on the peg at A, and the back sight to be 13·50, then, because we want to establish a peg at B 10 feet above A, we must deduct 10 feet from 13·50 = 3·50, which the staff should read when a peg has been driven level with the surface of the ground at B. The fore sight at *a* will be 0·17.

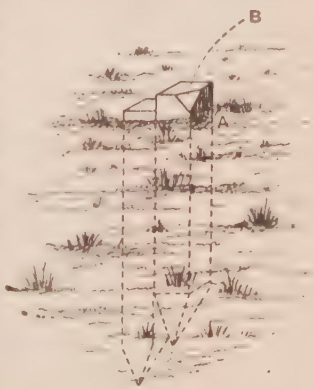


Fig. 265.

The instrument is moved beyond C (the staff remaining at *a*); and when adjusted the back sight is 12·85. Now the difference between the last back sight and the point B is 350 — 0·17 = 3·33, which is on account of the fresh altitude at *c*; therefore 10·00 — 3·33 = 6·67 feet, which is the difference; and if we deduct this from 12·85 (the new back sight), the staff held on a peg at C should

read 6·18 ; and as it is necessary to make a change, we determine the fore sight as 3·00, which gives a rise of 3·18 in favour of the next vertical altitude at D. At *b* the back sight is 13·12 ; and as we have 3·18 towards D, the rise from *b* will be 10·00 — 3·18

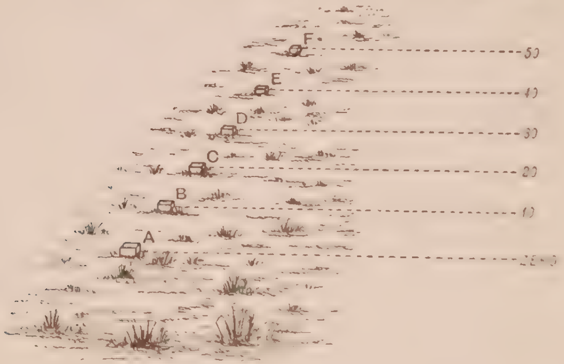


Fig. 266.

= 6·82, which, deducted from 13·12 — 6·82 = 6·30, the intermediate at D. Now the fore sight is 0·40, which is 5·90 towards the vertical interval at E ; the back sight at *c* is 9·10 ; and if from

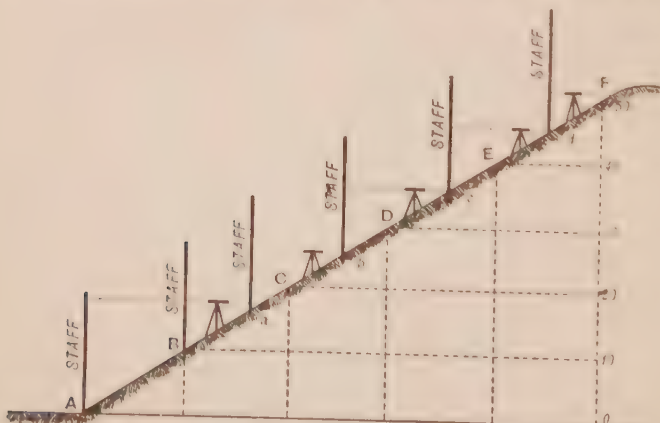


Fig. 267.

this be deducted the difference between 10·00 and 5·90, we shall get 5·00 as the intermediate at E, whilst the fore sight is 0·19 at *d* and 5·00 — 0·19 = 4·81 towards the last vertical interval. Here

the back-sight is 7·30, from which must be deducted = 5·19, or the difference between 10·00 and 4·81, which will give a reading at F of 2·11. I have thought it desirable to give this as a simple illustration, as being more readily understood. The following is the level-book :—

Back Sight.	Intermediate	Fore Sight.	Rise.	Fall.	Reduced Levels.	Distance.	Remarks.
13·50					0·00		B. M. on peg at A.
	3·50		10·00		10·00	—	On peg at B.
12·85		0·17	3·33		13·33		At *a*.
	6·18		6·67		20·00		,, C.
13·12		3·00	3·18		23·18		*b*.
	6·30		6 82		30·00		,, D.
9·10		·40	5·90		35·90		*c*.
	5·00		4·10		40·00		,, E.
7·30		0·19	4·81		44·81		*d*.
		2·11	5·19		50·00		,, F.
55·87		5·87	50·00				

CHAPTER XI.

SETTING OUT CURVES.

Practical surveyors are nowadays required to perform so many more duties than heretofore, that any work upon the subject of their duties would be incomplete if it did not treat upon the setting out of curves. It does not necessarily follow that these curves are only for railway work, as in the development of property it is often requisite to lay out new roads and boundaries, which, for economical and other reasons, frequently are required to take the form of regular curves.

The most accurate and satisfactory method of laying out curves is by means of a theodolite, but for approximate results the operation may be performed by tangents and offsets, or chords and ordinates.

Now in all cases a curve is used to connect two straight lines, whose relative positions are such that one forming an angle with

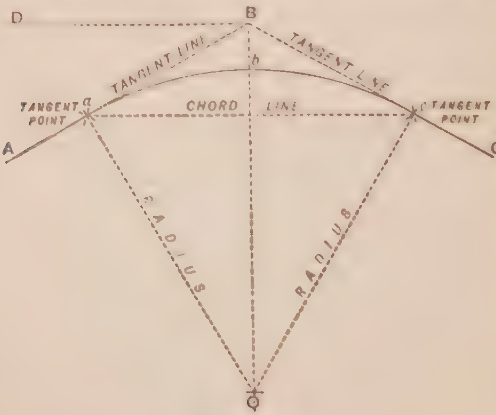


Fig. 268.

the other they intersect each other at some given point. In Fig. 268 it will be seen that the lines A a and C c intersect at the point B. It matters not how acute or obtuse the angle of intersection may

be, there is some curve, great or small, which will connect these two lines, and whose connection will be tangential therewith.

In considering a railway, as an illustration, it simply consists of a series of straight lines, whose directions form angles with each other, whereby it is necessary to connect each with the other by means of curves, as is illustrated in Fig. 269, by the five lines A B,

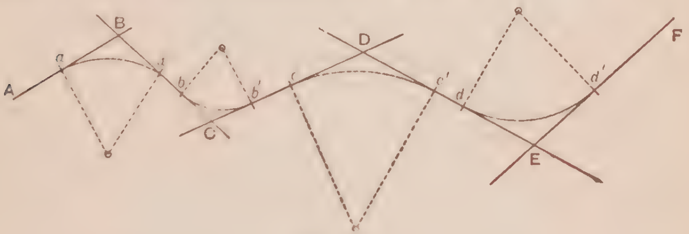


Fig. 269.

B C, C D, D E, E F, and four curves *a a′*, *b b′*, *c c′*, and *d d′*. Here we have the angles A B C, B C D, C D E, and D E F, without knowing the value of which it is impossible to set out the curves upon the ground.

It may be well here to mention that for railway work it is better to lay out these straight lines and make them the base-lines of the survey. This may be done either by traversing or, preferably, by taking the included angles with the theodolite. It need hardly be explained that for the purpose of taking up the features on the right and left hand of these lines a complete system of triangulation must be adopted.

Having obtained an accurate record of the relative positions of these straight lines, which should be plotted to as large a scale as possible, together with the details of the survey, it will then be possible to determine the various radii of the connecting curves.

Limit of Radii.—In speaking of the radii of curves, I may say that curves of less than 12 chains' radii are not desirable for railway work. I have known less, but for many reasons sharp curves are to be avoided. It is a very mistaken theory that curves of small radii enable the engineer to economise in the design of his work, or in other words to avoid undue severance of property; and it is a very questionable policy, for against a small saving in the purchase of the necessary land (which is settled once for all must be placed the constant wear and tear of the permanent way and rolling stock, which, if capitalised at a period of years, will prove a very formidable amount. Again, in these days of high speed it is absolutely out of the question to adopt sharp curves. There is no fixed rule to govern the limit of radius of curves, as

so much depends upon local and other circumstances, which it is not the province of this work to consider.

Preliminary.—Now to take a simple illustration, we will assume that in Fig. 268 the angle of intersection A B C is 135 deg.; now bisect this angle = 67 deg. 30 min., which should be deducted from 90 deg., the result will be the angle of deflection B *a* *c* = 22 deg. 30 min. = D B *a*. We have seen that the angles *a* B O, C B O = 67° 30′, therefore the line B O is the true bisection of the angle A B C, and is at right angles with the end line *a* *c*.

Now, supposing we assume the radius of one curve to be 30 chains, and it is required to find the radial point O; multiply the natural secant of the ∠ of deflection (= 22 deg. 30 min.) by the radius =

Nat. sec. 22° 30′ = 1·08244 × 30 = 32·4732 chains,

which is the distance from the apex B to the centre, of the curve O, and consequently 32·4732 − 30 = 2·4732 chains, or the distance (B *b*) from the apex of the curve to a point in the circumference of the arc at its point of bisection *b*. It is now necessary to determine the points of commencement and termination of the curve, which is arrived at by multiplying the natural tangent of the angle of deflection by the radius, which will give the length from the apex B to the commencement *a* and termination *c* of the curve. Thus

Nat. tan. 22·30=0·41425 × 30=12·4275 chains = lengths B *a*, B *c*.

We have thus the points of the commencement, centre, and termination of the curve, and may proceed to set out the other points by any of the methods to be hereafter described.

I propose, however, to continue the consideration of setting out this curve by means of a theodolite, being satisfied that it is not only the most reliable but most expeditious system. We can describe an arc of a circle corresponding with the radius of one curve on paper by finding the centre, and with a beam-compass or dividers we can draw the curve through the point *a* *b* and *c* (Fig. 268); but in the field we have to be content with points in the arc represented by short chords. Thus our English practice is to set out points at the end of every chain (66 ft.)

The straight lines *a* A, *c* C should be accurately prolonged to the intersection at B, where a stout peg should be driven and the exact point of intersection marked by a spike driven into the peg. The theodolite must now be adjusted over this peg, and the angle A B C must be taken, which we have assumed to be 135 deg. Now set the vernier to 67 deg. 30 min. and direct an assistant to carefully put a rod in the line B O. Next proceed to calculate the distance B *b*, and from B, having measured two chains towards O at the end of 2·4732 chains, fix a peg by means of the cross-wires of the telescope. which will be the exact centre of the curve. Next measure

the lengths B a, B c = 12·4275 chains, and with the cross-wires of the telescope fix a spike in each peg driven into the ground at a and c.

Tangent Points.—Having fixed these points a and c, direct an assistant to drive four smaller pegs round each, as in Figs. 270, 271, 272, so as to distinguish the commencement and termination of the curve from other points, thus :—

We next proceed to fix the theodolite at A, and, with the zero

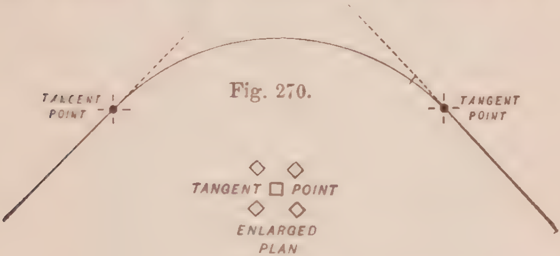


Fig. 270.

Fig. 271.

Fig. 272.

clamped at 360 deg., and the instrument properly adjusted, we are in a position to commence setting out the various points on the curve.

Tangential Angle.—It has been found by calculation, by eminent mathematicians, that if the constant 1719 is divided by the

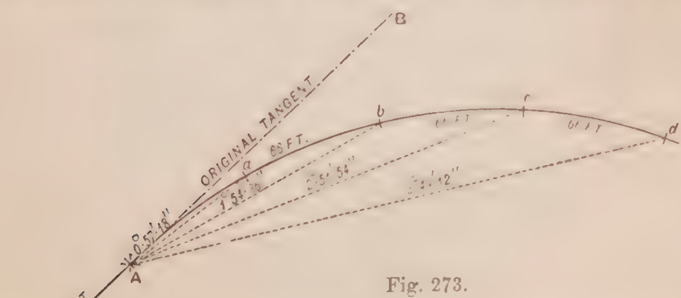


Fig. 273.

radius in chains it will give the first tangential angle B A a, Fig. 273. Therefore $\frac{1719}{30}$ = 57 min. 18 sec. ; consequently, with the instrument fixed at A, clamped at zero

and the telescope in line with the tangent A B, if the angle 57 min. 18 sec. is set in the instrument and a chain is measured from A, where the cross-wires cut the end of the chain is the first point on the curve *a*. The second point *b* is found by multiplying 57 min. 18 sec. by 2, the third *c* by 3, the fourth *d* by 4, and so on. I prefer, however, to keep a record of the various angles at the points *a*, *b*, *c*, *d*, &c., in my book, thus :—

	Deg.	Min.	Sec.
1st tangential $\angle = \frac{1719}{30} =$	0	57	18
	0	57	18
2nd ,,	1	54	36
	0	57	18
3rd ,,	2	51	54
	0	57	18
4th ,,	3	49	12
	0	57	18
5th ,,	4	46	30 and so on.

So that assuming the theodolite will command five points (or more) in the curve, if the vernier is set at the various angles in the preceding table, at the end of a chain measured from the last peg the intersection of the cross-wires will give the required points.

Length of Curve.—I will here leave this subject for a moment to explain a very important matter, and that is, to ascertain the length of the curve. We have seen that the angle of deflection (Fig. 268) B *a c* is 22 deg. 30 min., and the radius of the curve is 30 chains. Also the tangential angle for the first part is 57·30 min. or 57 min. 18 sec. Now if we divide the angle of deflection by the tangential angle, it will give us the number of chords in the curve. Thus $\frac{81{,}000}{3{,}438}$ = 23·50 = the number of chords. This may be found also by the following rule in Molesworth :—

when x = half-angle of intersection = 67° 30′,
A = tangential angle in minutes = 0° 57·30′*
R = radius of curve.
L = length of curve.
N = number of chords.

Then
$$N = \frac{5400 - x}{A} = 23{\cdot}56$$

and the length of the curve may be found by the following formula :—

$$L = {\cdot}000582\ R\ (5400 - x) = 23{\cdot}57 \text{ chains.}$$

* This is 57 minutes and decimal 30 of a minute, not 57 minutes 30 seconds.

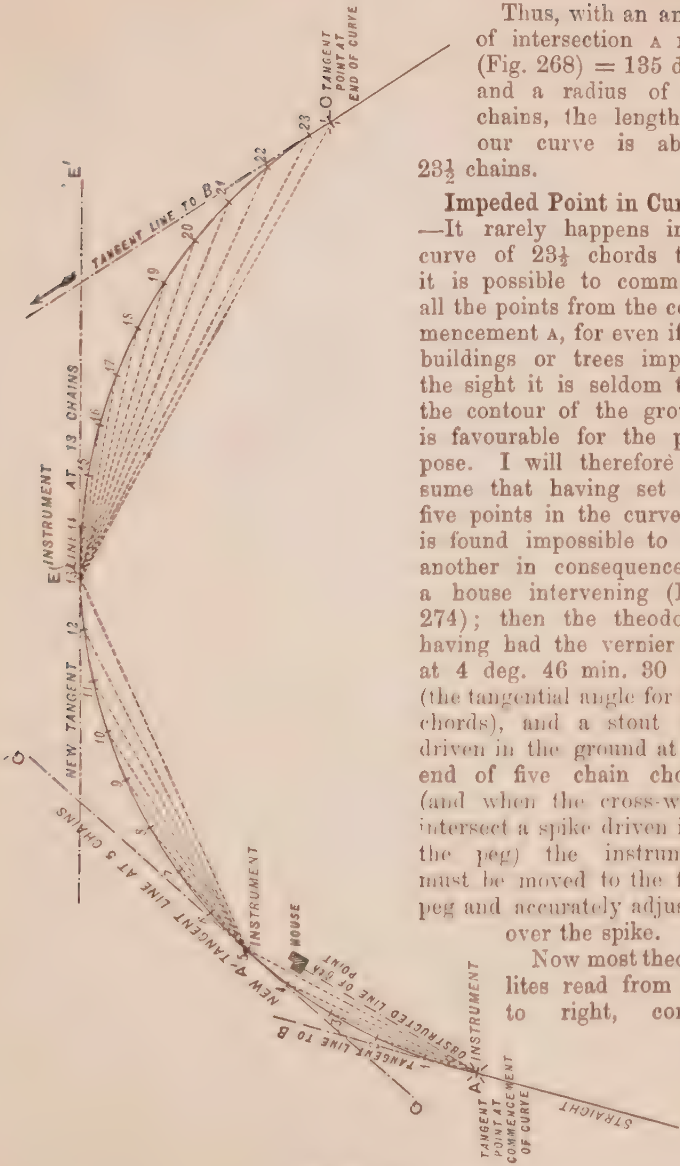


Fig. 274.

Thus, with an angle of intersection A B C (Fig. 268) = 135 deg. and a radius of 30 chains, the length of our curve is about $23\frac{1}{2}$ chains.

Impeded Point in Curve.—It rarely happens in a curve of $23\frac{1}{2}$ chords that it is possible to command all the points from the commencement A, for even if no buildings or trees impede the sight it is seldom that the contour of the ground is favourable for the purpose. I will therefore assume that having set out five points in the curve, it is found impossible to see another in consequence of a house intervening (Fig. 274); then the theodolite having had the vernier set at 4 deg. 46 min. 30 sec. (the tangential angle for five chords), and a stout peg driven in the ground at the end of five chain chords (and when the cross-wires intersect a spike driven into the peg) the instrument must be moved to the fifth peg and accurately adjusted over the spike.

Now most theodolites read from left to right, conse-

quently, having fixed the instrument at A′ (on the fifth peg) we must deduct the tangential angle for five chains, or 4° 46′ 30″ from 360° = 355° 13′ 30″, and if the vernier be set to this angle and the telescope directed to a rod held at A, in the line of chord A′ A (Fig. 274), when the limb is clamped and adjusted on the point and the vernier turned to zero, the telescope now points in the direction G G′, which is the new tangent line for the succeeding points after five chains on the curve. From this point (A′) we now proceed to set out the sixth and succeeding points *de novo*, so that the following will be the tangential angles, until we are again prevented from seeing further than the thirteenth peg.

		Deg.	Min.	Sec.
6th tangential L. = $\frac{1719}{30}$ =		0	57	18
			57	18
7th	”	1	54	36
			57	18
8th	”	2	51	54
			57	18
9th	”	3	49	12
			57	18
10th	”	4	46	30
			57	18
11th	”	5	43	48
			57	18
12th	”	6	41	06
			57	18
13th	”	7	38	24

This brings us to the thirteenth point of the curve, and the instrument has fixed eight tangential angles or 7 deg. 38 min. 24 sec., and we can see no further from A′, consequently the instrument must be moved to E (the thirteenth peg) and adjusted. The tangential ∠ G′ A′ E, or 7° 38′ 24″, must be deducted from 360° = 352° 21′ 36″. The telescope must be directed to A′, and the limb being clamped in this position, the vernier turned to zero when we have a new tangent line E E′, from which we must proceed to set out the remaining 10½ points, as follows :—

	Deg.	Min.	Sec.
14th tangential angle $\frac{1719}{30}$ =	0	57	18
		57	18
15th ,,	1	54	36
		57	18
16th ,,	2	51	54
		57	18
17th ,,	3	49	12
		57	18
18th ,,	4	46	30
		57	18
19th ,,	5	43	48
		57	18
20th ,,	6	41	06
		57	18
21st ,,	7	38	24
		57	18
22nd ,,	8	35	42
		57	18
23rd ,,	9	33	00

Thus we have set out twenty-three points in the curve, and now have not another complete chord of 66 ft., but only 0·56 chains, and consequently to find the tangential angle for this length we must multiply 57′ 18″ by ·56 = 32′ 05″, which must be added to 9° 33′ = 10° 05′ 05″ = tangential angle for 10½ chains from E to C, the termination of the curve, and the sum of all the tangential angles, as follows, equals the total angle of deflection. Thus

$$\begin{array}{l} 4^\circ\ 46'\ 30'' \\ 7^\circ\ 38'\ 24'' \\ \underline{10^\circ\ 05'\ 05''} = 22^\circ\ 29'\ 59'' \text{ or } 22\tfrac{1}{2}^\circ \text{ practically.} \end{array}$$

Apex Inaccessible.—Now, we will suppose that some building, or possibly a stream, prevents the prolongation of the tangents A B, B C (Fig. 275).

At any points on the lines A B, B C set up as at A and D and

C and E, lines at right angles to A B, B C. Measure equal lengths, say two chains A a, D d, and C c, E e. Through these points a and d and c and e draw the lines a d and c e (which are parallel to A B

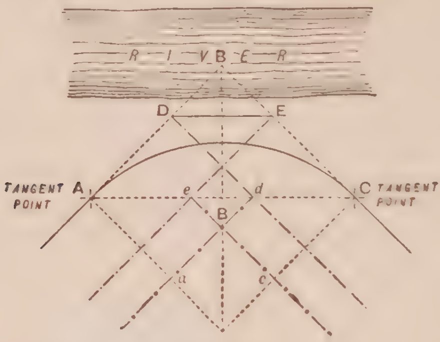


Fig. 275.

and B C), and the intersection at B′ is the angle A B C required. To prove this draw the straight line D E parallel to the chord-line A C. Then 180 deg. taken from the sum of the angles A D E, C E D, or A D E + C E D − 180° = angle a B′ c = A B C.

But we have yet to find the points A and C on the curve, and although we have ascertained the angle of intersection a B′ c = A B C, yet, as B is inaccessible, we must calculate the lengths B D, D E by the following formulæ:—

$$\text{BD} = \text{DE} \times \frac{\sin.\ \text{CED}}{\sin.\ \text{ABC}};\quad \text{BE} = \text{DE}\,\frac{\sin.\ \text{ADE}}{\sin.\ \text{ABC}}$$

Now we will suppose the angles A D E, C E D = 157·30° and D E = 12 chains,

$$\text{Then ADE} + \text{CED} - 180° = \text{A}$$
$$\text{Or}\quad 157{\cdot}30° + 157{\cdot}30° - 180°$$
$$= 315{\cdot}00° - 180° = 135° = \text{A}.$$

We want now the lengths B D

$$= \text{DE} \times \frac{\sin.\ \text{CED}}{\sin.\ \text{ABC}} =$$

$$12 \times \frac{\sin.\ 157{\cdot}30}{\sin.\ 135{\cdot}00} = 12 \times \frac{\sin.\ 22{\cdot}30}{\sin.\ 45{\cdot}00}$$

$$= 12 \times \frac{{\cdot}38267}{{\cdot}70711} = 12 \times {\cdot}549 = 6{\cdot}48 \text{ chains}$$

and as B D = B E in the lengths, B E also = 6·48 chain.

We have seen that the angle $a\,B'\,c = \angle$ A B C and $\angle$ A B e = **135°**, so that a curve of 30 chains' radius will be under precisely the same circumstances, with the exception that B being inaccessible we have to establish the tangent point A and C by deducting the lengths B D and B E from the calculated lengths B A, B C, which we have found to be 12·42 chains; therefore, 12·42 – 6·48 = 5·94 chains = A D, E C.

I would here remark that it does not often happen that the commencement of a curve is exactly at even chainage. We will suppose that one curve commences at 6 miles 27·32 chains; consequently, taking the same example as on page 231, where the radius of the curve is 30 chains, the angle of intersection 135 deg., the length from the apex to the points A and C 12·4275 chains, and the length of the curve 23½ chains, now 32 links from 100 = 68 links, and consequently the first point on our curve will not be the tangential angle for 1 chain but their fraction. Therefore (see Fig. 274)—

	Deg.	Min.	Sec.
1st tangential L. = $\dfrac{1719 \times \cdot 68}{30}$ =		38	57
		57	18
2nd ,, =	1	36	15
		57	18
3rd ,, =	2	33	33
		57	18
4th ,, =	3	30	51
		57	18
5th ,, =	4	28	09
Add to this the tan $\angle$ for 18 chords	17	11	24
Tangential $\angle$'s for 22·61 chains	21	39	33
Then 23·50 – 22.68 = ·82;			
So that the fractional chord is			
·82 ∴ $\dfrac{1719 \times 82}{30}$ =		46	29
	22	26	02

Setting out Curves with two Theodolites.—This is at once the quickest, most accurate, and most satisfactory method with the instrument by which the points on the curve may be found without measurement, and this system is especially adapted to cases where

a river, a part of a lake, or other obstacles prevent the possibility of using the chain; also in very hilly ground, where the measurement of the chord-lines would be not only attended with difficulty, but liability to inaccuracy.

Fig. 276 is a simple illustration of this method. The straight lines if produced to B would intersect in the bay, whilst a portion of the curve will be also in the bay, and it is required to set out the points of the curve at 1, 2, 3, 4, 5, and 6. By the method explained on page 234, and illustrated by Fig. 275, the angle of intersection may be obtained and the points A and C fixed on the

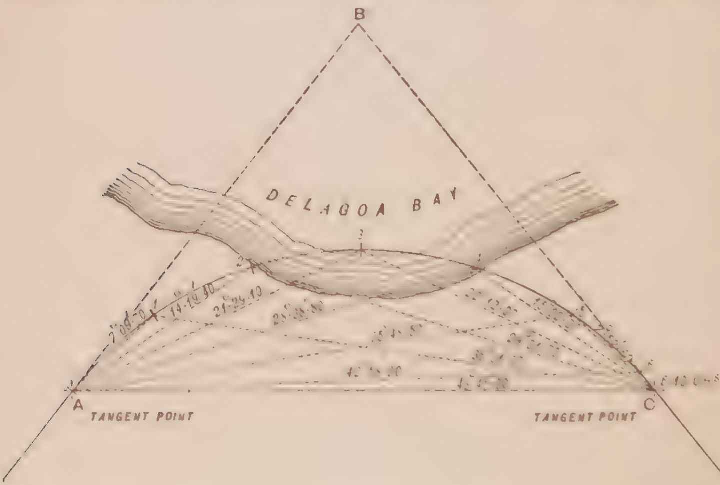


Fig. 276.

commencement and termination of the curve. At each of these points a theodolite should be fixed and adjusted to their respective tangent lines A B and C B.

In this example we will assume the radius to be 8 chains and the angle A B C 92 deg. 30·00 min., and the chords 2 chains each. Thus the angle of deflection is 43 deg. 45 min. and the tangential angle for each of the two chords is 7 deg. 09·70 min., and the length of the curve is 12·20 chains.

Now for the first point on the curve we have 7 deg. 09·70 min., to be adjusted in the theodolite at A, and seeing that there are 6·10 chords we shall have to fix the upper plate of the theodolite at C. In the angle of 5·10 chords of two chains each = 36 deg. 31·37 min. the intersection of the cross-wires of each of these instruments will give the first point on the curve as represented by the lines A 1, C 1. In the second point the theodolite at

A will record 14 deg. 19 min. 40 sec., whilst that at C will have to be adjusted to 29 deg. 21·70 min., and the intersection of the cross-wires will give the second point on the curve as shown by the line A 2, C 2. The third point will be 21 deg. 29·10 min. at A, and 22 deg. 12·07 min. at C., representing the intersection of the lines A 3, C 3. The fourth point will be 28 deg. 38·80 min. at A, and 15 deg. 02·37 min. at C. The fifth point will be 35 deg. 48·50 min. at A, and 7 deg. 52·60 min. at C. Whilst the sixth point will be 42 deg. 58·20 min. at A, and 00 deg. 43·00 min. at C. And the last point will be 43 deg. 45 min., or the angle B A C. The following is a tabulated statement of the various angles; at the intersection of the cross-wires are the various points on the curve.

Theodolite at A. Tan. A B.			Theodolite at C. Tan. C B.		
Angle B A 1	=	7° 09·70′	Angle B C 1	=	36° 31·37′
" B A 2	=	14° 19·40′	" B C 2	=	29° 21·70′
" B A 3	=	21° 29·10′	" B C 3	=	22° 12·07′
" B A 4	=	28° 38·80′	" B C 4	=	15° 02·37′
" B A 5	=	35° 48·50′	" B C 5	=	7° 52·60′
" B A 6	=	42° 58·20′	" B C 6	=	0° 43·00′
" B A C	=	43° 45·00′			

Now if an assistant be directed to proceed to above the points of intersection of the lines B A 1 and B C 1, &c., he should place a peg at the identical point as directed by the observer at each theodolite.

Curves of different Radii.—It may happen that for good reasons, whilst it may be desirable to traverse a certain portion of the ground by a curve of say 60 chains radius, yet an obstruction may occur which involves either the diminution of the radius of the curve, or (what is frequently done) the stoppage of the original curve at a point, and after a short length of straight line the adoption of a curve of sharper radius in order to avoid the obstruction. Thus in Fig. 277 we see that after setting out a certain distance from A to *b* with a radius of 50 chains, that from this latter point it is necessary to reduce the radius to 40 chains. Now, assuming that we have set out 8 chords from A, then the tangential angle B A *b* will be 28 deg. 38·96 min., consequently if we remove the theodolite from A to *b* and set the vernier at 331 deg. 21·04 min. (being 360 deg. — 28 deg. 38·96 min., rendered necessary as we are now working the upper plate from right to left), and clamp the two plates, then direct the telescope on to A, and clamping the lower and unclamping the upper plate, if we fix the latter at zero,

we shall then obtain a tangent line S b T common to the two curves, and from b, which is termed *the point of compound curvature*, we

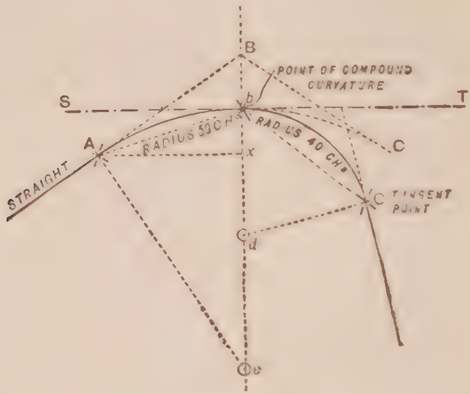


Fig. 277.

may now proceed to set out the tangential angles for the 40-chain curve.

Curves of Contraflexure.—"Reverse" curves or curves of contraflexure, as Fig. 278, are set out by establishing a common tangent-line F G by the same process as just described, and setting

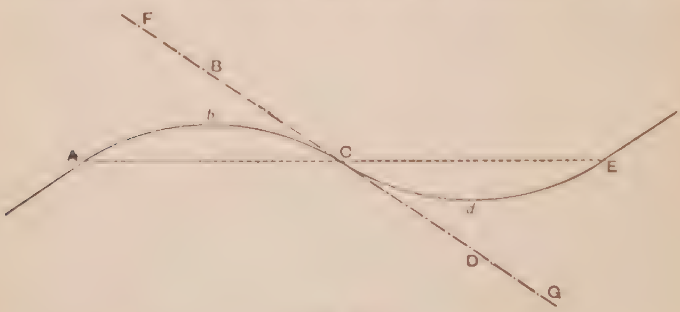


Fig. 278.

out tangential angles from right to left from C, in which case each angle for one chord must be consecutively deducted from 360 deg.

It should here be stated that a length of straight line, usually two chains, should always intervene between any curves, whether of similar or contraflexure, as it is under very exceptional circum-

stances—at least as far as English practice is concerned—that one curve proceeds directly from another. Upon the Continent it is, I am aware, customary to use parabolic curves, but a whole library of scientific reasoning and deductions will not supersede the result of our own practical experience; and seeing that we have express trains running at more than double the highest speed of the Continental railways, I think we may fairly assume that the principles which govern our own system are well founded.

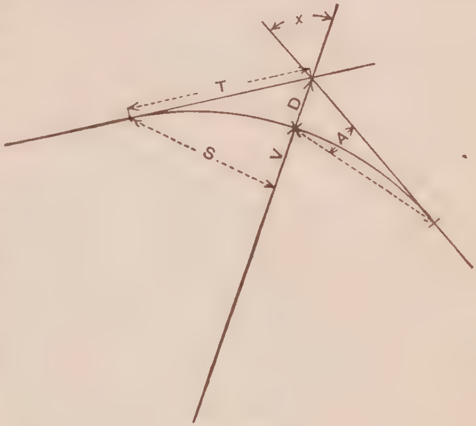


Fig. 279.

The following formula (Fig. 279) is given in Molesworth, which may be useful :—

R = Radius of curve.
T = Length of tangent.
x = Half-angle of intersection.
D = Distance of centre of curve from intersection.
C = Any chord.
A = Tangential angle of c in minutes.

$$R = \frac{1719\ c}{A}.$$

$$R = T\ (\tan x).$$

$$T = R\ (\text{cotan}\ x).$$

$$D = R\ (\text{cosec}\ x - 1).$$

$$A = \frac{1719\ c}{R}.$$

$$S = R\ (\text{cosine}\ x).$$

$$V = R\ (\text{coversine}\ x).$$

$$\text{Number of chords in the curve} = \frac{5400 - x}{A}.$$

$$\text{Length of curve} = \cdot 000582\ R\ (5400 - x).$$

NOTE.—x and A in the two preceding formulæ must be expressed in minutes.

TABLE OF TANGENTIAL ANGLES FOR ONE CHAIN CHORDS.

Radius of Curve	Tangntl. Angle.	Radius of Curve.	Tangntl. Angle.	Radius of Curve.	Tangntl. Angle.	Radius of Curve.	Tangntl. Angle.
	deg. min		deg. min.		deg. min		deg. min
5	5 43·8	15	1 54·6	40	0 42·97	1 mile	0 21·48
8	3 34·87	20	1 25·95	45	38·2	1¼ "	17·19
9	3 11	25	1 8·.6	50	34·38	1½ "	14·33
10	2 51·9	30	57·3	60	28·65	1¾ "	12·28
12	2 23·25	35	49·11	70	24·55	2 "	10·74

"NOTE.—The angle for 2 chain chords is double the angle of 1-chain chords. The angle for ½-chain chords is half the angle for 1-chain chords.

"Curves of less than 20 chains' radius should be set out in ½-chain chords. Curves of more than 1 mile radius may be set out in 2-chain chords.

"The angles in the above table are in degrees, minutes, and decimals of minutes."

Setting out Curves by Offsets.—I shall very briefly consider these methods, as experience has clearly proved that they can only be used in cases where accuracy is not important.

The most common system is by means of an offset from a new tangent-line at each point on the curve, as in Fig. 280.

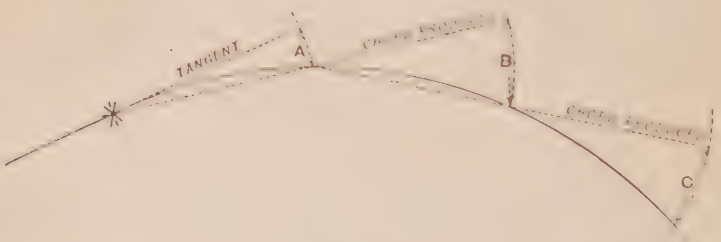


Fig. 280.

Now suppose we have a curve of 20 chains' radius which it is desired to set out by offsets at every chain.

The fundamental principles involved in the consideration of the formulæ are very simple. If, as in Fig. 281, we take the arc of a circle, of we will say 4 chains' radius, and divide it into three or more chords, as A B, B C, C D, &c., and from each of the points A, B, C, D draw the radial lines A O, B O, C O, D O, &c.; now a tangent line must be at right angles to a line drawn from the centre

of the circle to the point in the arc where it impinges, consequently A′ A b is at an angle of 90° with A O, and so is the line B c' with

Fig. 281.

B O, and C d' with C O. The chord A B being drawn and the angle A O B being bisected, we have A O x = B O x.

Now in the triangle A O B, O A B + O B A + A O B = 180°; and O A x + O x A + A O x = O B x + O x B + B O x = 180°. But A b is at right angles to the radial line O A, and if produced to c, because B c' must be at right angles to O B, as C d' is to O C, &c., so the angles c B C and d C D, &c., are double the angles b A B.

The formulæ for calculating the offsets are based upon the following :—

$$b\,\text{B} = \frac{\text{A B} \times \text{A B}}{2 \cdot \text{O A}} = \frac{\text{A B}^2}{2 \times \text{O A}}$$

(1) 1st offset . . . . b B $= \dfrac{\text{Chord}^2}{2\ \text{Radius}}$.

(2) 2nd and succeeding offsets . $= \dfrac{\text{Chord}^2}{\text{Radius}}$.

It will be seen from the foregoing that the result of the second equation will be double that of the first. But we have seen that the angles c B C, d C D, &c., are double that of b A B, consequently b B is half c C, and c c', and c' C each = b B, referring, therefore, to the curve of 20 chains' radius, if rods are placed perfectly perpen-

dicular at A′ and A, and the surveyor, standing some few yards away from A′, ranges a rod in line with A′ A held at the end of a chain from A at *b*.

Now for the first offset we have—

$$\frac{\text{Chord}^2}{2\text{ Radius}} = \frac{66^2}{66 \times 20 \times 2} = \frac{4356}{2640} = 1{\cdot}65 \text{ ft.} = 1'\ 7\tfrac{3}{4}'',$$

And for the second and subsequent offsets—

$$\frac{\text{Chord}^2}{\text{Radius}} = \frac{4356}{1320} = 3{\cdot}30 \text{ ft.} = 3'\ 3\tfrac{1}{2}''.$$

To set out a curve by this or the following methods requires the very greatest care and accuracy. The way I have always done has been to get a lath of good hard wood, a little longer than the longest offset (Fig. 282), with a hollow sufficient to fit into the arrow;* the chain is now swung from A towards B, and is held at the intersec-

Fig. 282.

tion of the offset-staff *b* B and its end at B. The slightest error will accumulate throughout all subsequent operations. A rod is now fixed at B, the first point of the curve, and the chord-line A B is

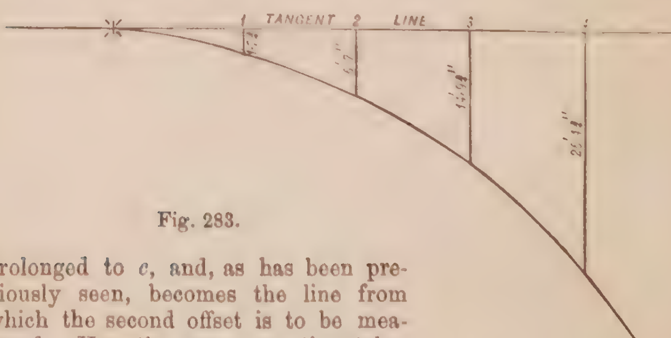


Fig. 283.

prolonged to *c*, and, as has been previously seen, becomes the line from which the second offset is to be measured. Here the same operation takes place, only the offset is 3′ 3½″ from *c* to C and at all subsequent points until the last point in the curve, when it is the same as *b* B.

* When the point *b* or *c* or *d*, &c., has been accurately determined an arrow should be stuck in the exact spot, and the offset-staff should be held at this arrow.

It is better to temporarily mark all the points on the curve before driving in pegs, to see whether it works round all right; if not the process must be repeated until it does so.

It should be quite understood that the first offset is at right angles to the line A *b*, but the second and following ones are measured from *c* to C, *d* to D, and so on.

Setting out Curves from same Tangent.—Another method of setting out a curve by offsets is from the same tangent (Fig. 283), the offsets being all at right angles thereto. In this system the first offset is found by the same rule as the preceding, viz., $\frac{\text{Chord}^2}{2 \text{ Radius}}$; and the subsequent offsets are this result multiplied by the square of the number of points. Thus for a 20-feet curve:—

	Inches.		Ft.	In.
1st offset . .	19·80	=	1	$7\frac{3}{4}$.
2nd ,, . .	19·80 × 4	=	6	7.
3rd ,, . .	19·80 × 9	=	14	$9\frac{3}{4}$.
4th ,, . .	19·80 × 16	=	26	$4\frac{3}{4}$.
5th ,, . .	19·80 × 25	=	41	3.

&c., &c., &c.

Setting out Curves by means of Ordinates.—For small curves this is possibly the most accurate method, consisting of setting up, upon a chord-line, ordinates, or lines at right angles thereto, to various points in the curve as illustrated in Fig. 284.

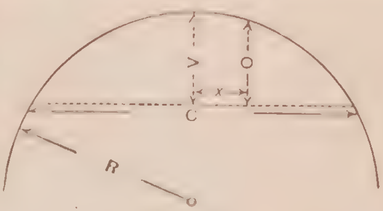


Fig. 284.

In Fig. 284, the letters refer as follows:—

C = Chord.
V = Versed sine.
R = Radius.
X = Distance of ordinate from centre of chord.
O = Length of ordinate.

Then,

$$V = R - \sqrt{R^2 - (\tfrac{1}{2} C)^2}.$$
$$O = \sqrt{R^2 - X^2} - (R - V).$$

I have not attempted to consider any of the other systems, although they look very well on paper, and many books are ornamented

with the abstruse calculations they involve, but "an ounce of practice is worth a pound of theory," and my experience induces me to say that, for mere approximation, the surveyor may use such of the methods by measurement only as I have described; but for accuracy and expedition in the field, and the assurance that you will be able to plot your curves upon your survey in the office, then the only reliable system is that advocated at the commencement of this chapter, and illustrated by Figs. 268 to 276.

CHAPTER XII.

OFFICE WORK.

NEXT to proficiency in all field operations, office work is of great importance. A man may be ever so clever a surveyor, and even renowned for his accuracy, but unless he can portray the results of his observations graphically, so that the least initiated can easily comprehend their meaning, his work will be deprived of a very considerable amount of merit. He may be an excellent draughtsman in some ways, yet fail utterly to give adequate expression to days or even weeks of patient labour, if he cannot in a minimised form give a true reproduction of his operations.

Necessity for System.—System is a very potent element in all branches of surveying, especially draughtsmanship. Those beautiful Ordnance plans, in various scales, are the result of accuracy in the field and methodical elaboration in the office. Take even the 1-inch map, and it seems to speak for itself; whilst the larger scales enable the authorities, by their perfect administration, to delineate the most minute features, of which these plans are faithful representations.

George Stephenson, in the early days of railway enterprise, was wont to express the opinion that a map or detailed drawing should be so executed as to enable either to be read "like a book;" and there is no reason whatever why a survey should not.

To this end, I wish to give a few preliminary hints which may be of service to the student.

Roughly Plot the Survey Lines.—1st. Roughly plot the chief lines of your survey to see what form it will take, so that you may arrange it symmetrically upon the paper upon which you intend to plot it.

Let the Paper be well seasoned.—2nd. Provide a piece of well-seasoned paper—Whatman's double-elephant, cold-pressed, is the best—and the paper should be mounted upon holland.

Draw a Scale on Paper before commencing.—3rd. Before commencing to plot your survey draw the scale upon the paper, so that you may apply your boxwood scales from time to time to ascertain whether the paper has been affected by temperature.

Boxwood Scales best.—4th. Boxwood scales are preferable to ivory.

Plot Survey North and South.—5th. Always plot your survey looking north, so that the top, bottom, left, and right respectively represent north, south, west, and east.

Paper Perfectly Flat.—6th. Keep your paper perfectly flat, and endeavour not to move it from the drawing table during the process of plotting.

Laying down the Survey Lines on Paper.—7th. Having made a rough plan of your principal lines, proceed to lay them down carefully upon the permanent paper, commencing with your principal base-lines.

Check Measurement.—8th. Measure each line from left to right (using a pricker) upon a faint pencil-line, and check back from right to left and test its accuracy.

Marking Stations.—9th. Mark round the puncture representing a station with a pencil-ring thus ʘ, and opposite each station in faint pencil, with the distance, thus ——ʘ——.

Straight Edge.—10th. Having plotted your principal base and survey lines with a steel straight-edge (the longer the better), proceed to draw in these with a fine red line * (carmine or crimson lake), being specially careful that the lines are drawn accurately between the points only.

Never Plot from Pencil Lines.—11th. Under no circumstances plot your offsets or any detail lines from pencil chain-lines.

As to Plotting Long Lines.—12th. If the base or any other lines are longer than your straight-edge do not seek to produce the line hand-over-hand-wise, but take a silk thread and stretch it tightly between the extreme ends, and with a pricker (held perfectly vertical) make punctures at frequent intervening points, then you may apply the straight-edge, and be sure you have as true a line as is possible.

Plot all Survey Lines first.—It is much better to plot all the survey lines previous to commencing details, as any error, if detected, may be adjusted by re-measurement upon the ground, which might seriously affect the position of certain points of offset.

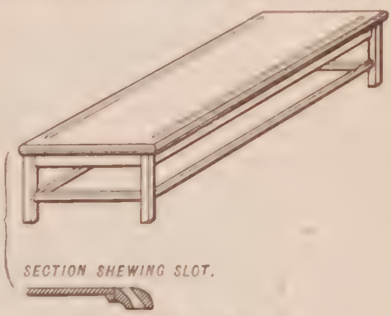
Plot each Day's Work as soon as possible.—Generally speaking it is better to plot each day's work at once. I do not say the same evening, for arduous duties in the field (often upon a very meagre meal) and a heavy feed on one's return from work are not con-

* A good surveyor need never be afraid of having the survey-lines upon his plan.

ducive to the patience, clearness of brain, or energy required for the purpose. On a large survey I recommend alternate days for field and office work, or using fine weather for the former, for say two or three days, and devoting wet days to office work.

Equipment of Office.—Now as to the equipment of an office. I differ entirely from those who argue that a surveyor who may have to take up temporary quarters at an hotel or inn, near the scene of his field operations, should plot his work under the very inconvenient circumstances often attending his sojourn. I am not speaking of a small survey, which may be plotted almost anywhere, and it is certainly preferable to do plotting in close proximity to the work rather than at a distance, in case of any mistakes in the chaining. But on a large survey it would be next to impossible to expect at an inn such facilities for plotting the work as are necessary, unless a room be specially engaged and fitted up for the purpose. This, however, must entirely depend upon circumstances, and no general rule can be laid down. Assuming, however, that arrangements of a satisfactory nature can be made, it is necessary for us to consider what are the necessary adjuncts of the office.

Drawing Tables.—1st. The drawing table is of great importance. It should be made of well seasoned timber and free from all imperfections, such as knots, &c.; it should be perfectly joined and clamped, and planed to an even surface. A convenient size is 8 ft. long by 4 ft. wide, and it should be supported upon a substantial under-framing with legs, *not trestles*. The edge all round should have a bull-nose from 3 to 4 in. deep, and it is better to have a slot lengthwise on each side, so that the paper, if longer than the board, may pass through, and thus be protected from creasing during the process of plotting (see Figs. 285 and 286).



Figs. 285 and 286.

The paper should be held down by lead weights, 3″ × 2″ × 1″ (weighing about 2½ lbs.), covered with cloth or, preferably, wash-leather, and care should be observed in resting them, even so covered, by placing them on pieces of waste paper, in case of any defect in the covering, or dirt. I have already stated that a steel straight-edge should be provided, as long as possible (say 6 ft.), having a bevelled edge. This straight-edge should when done with

each day be carefully wiped, as the moisture of the hand is productive of rust, and be placed either in a specially constructed case lined with green baize, or hung up in a dry place, encased in wash-leather or brown paper, to protect it from damp.

Scales.—A box of six boxwood scales, 12 in. long, with the accompanying offset scales, are indispensable. These scales are, one, two, three, four, five, and six chains to one inch on one side and corresponding feet on the other side—that is to say the full length of the scale of 12 in. represents twelve chains on one side and 792 ft. on the other; with the 2-chain scale, 24 chains and 1,584 ft.; with 3-chain, 36 chains or 2,376 ft.; with 4-chain, 48 chains or 3,168 ft.; with 5-chain, 60 chains or 3,960 ft.; and with a 6-chain, 72 chains or 4,752 ft. The offset scales are 2 in. long, representing 2, 4, 6, 8, 10, and 12 chains, or 132, 264, 396, 528, 660, and 792 ft. Boxwood scales are more reliable than ivory, and I prefer them to vulcanite. Always wipe them well before and after use, as the moisture of the hands encourages them to collect dirt.

Pricker.—All surveys should be plotted with a pricker with as fine a point as possible, and care should be taken to avoid making either too many or too large punctures, and round those required for further reference I always mark lightly with a pencil thus ⌒.

Pencils.—Only the best quality of lead should be used to plot work. HHH or HHHHH are the best; and don't lean too hard upon the pencil, as by so doing you make an indentation as well as a line.

Points of Pencils.—As to the best form of point for a pencil, I cannot say that I am very much enamoured of the chisel-shape. It certainly marks well against the straight-edge, and for mechanical drawing is much the best; but for plotting a survey, if (as it always should) the pencil is held perfectly vertical and a fine point kept, I think it is easier and better to manipulate.

Protractors.—The best form of protractor is circular, of as large

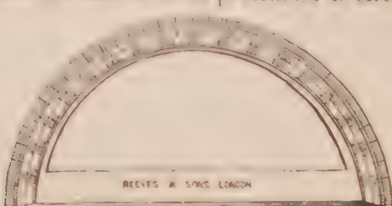


Fig. 287.

a diameter as possible. Electrum or brass protractors are best, of which there are various kinds. Figs. 287, 288, and 289

represent the simplest types, but for extensive work there are protractors having arms, at the end of each of which is a very fine pricker, and the instrument is so arranged that the centre of the

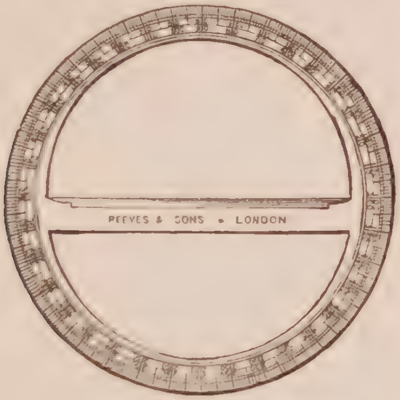


Fig. 288.

protractor being adjusted to the point of intersection, the arms are in line on either side with this centre, and may be fixed upon the line (Fig. 290). It has a glass disc in the centre, with lines at right angles to each other, which enables the instrument to be adjusted

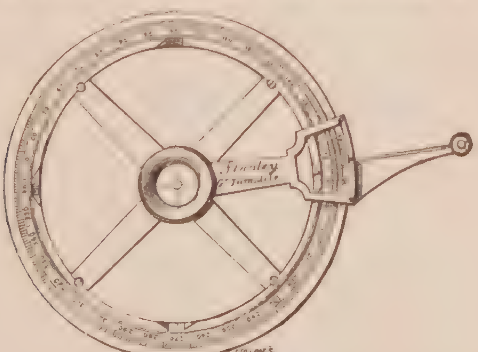


Fig. 289.

to any point on the survey-line. An arm *b*, working from a collar attached to the centre, is governed by a slow-motion screw *f* which actuates the arms *a a*, and when not in use may be folded over as shown. Another form of protractor which makes its appearance at all times is what is called the "ivory" or "military" protractor,

Fig. 291. It is a wonderful combination, and for portability and

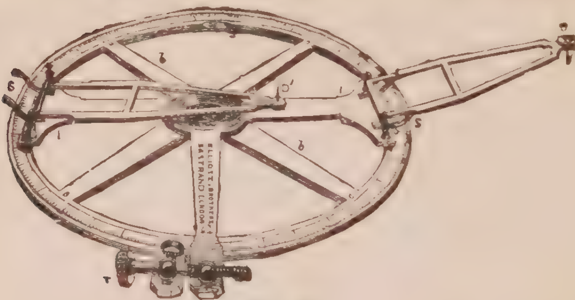


Fig. 290.

general utility (except for the purpose for which it is made) it is

Fig 291.

to be commended. For plotting a survey I should say do not use it except to ink in the boundaries, &c.

Beam Compasses.—For striking arcs of large radii such as are often required in plotting a chain survey, ordinary compasses are useless even with the lengthening bar. For such purposes these arcs should be described by means of beam compasses or trammels (see Fig. 292). This excellent instrument consists of two brass boxes, each having a movable plate parallel with its vertical side, which is actuated by screws *a a*, so that it can be pressed tight against the mahogany * beam A. One of these brass boxes has a slow movement screw D which enables the point C to be slightly moved at pleasure, whereby it may be adjusted to a hair's breadth. The points may be removed at either end, and pen and pencil ones substituted.

How to use the Beam Compass.—The best way to manipulate the beam compass is to draw a pencil line, and upon this to carefully measure the required length with a scale, and then to apply the compass by moving the boxes approximately along the beam so that the points are near the mark, then clamp the screws *a a′*, and with the slow-motion screw D get the exact position.

* These beams are made in any fair length of well-seasoned mahogany, having a "T" head to stiffen them.

Great Care in striking an Arc.—Great care is required in striking an arc with beam compasses, as at first, until one is accus-

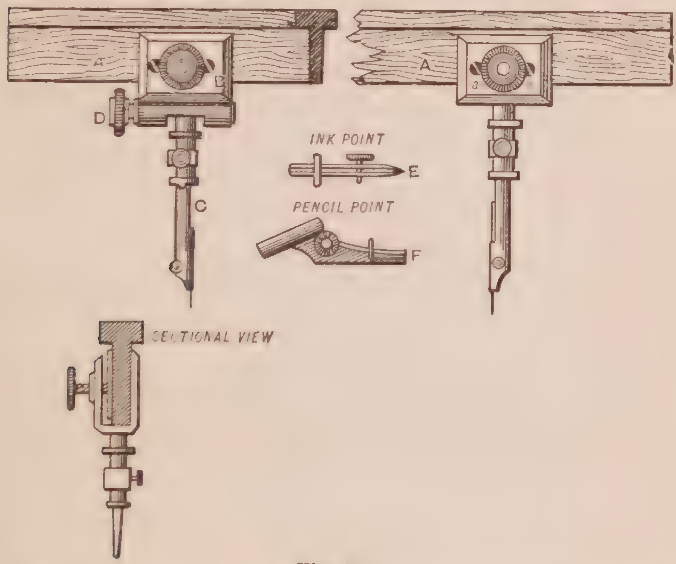


Fig. 292.

tomed to their use, they appear clumsy. Place the point of one end upon the station, holding the box lightly with the left hand, whilst with the right you guide the other box in the direction required, taking care not to press heavily upon the box. Thus if upon the line A B (Fig. 293), which is 1,260 links long, we wish to determine the point C, we must measure on a pencil line the length A C = 1,430 links, and placing the point at A describe an arc at C. And again with the length B C adjusted in the compasses, viz. 1,825 links, we describe an arc intersecting the other arc at C, and from A and B we draw the lines A C, B C respectively. Should there be a check or tie line, as from A to D, when on B C we must strike the arc whose radius is 1,115 links, corresponding with the distance which the station D is from B, and draw the line A D, which when scaled should correspond with our measurements in the field, viz. 1,040 links.

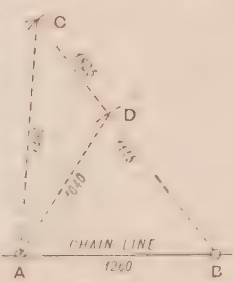


Fig. 293.

Pricker or Needle Holder.—No survey should be plotted without a pricker or needle-holder, as the finest puncture is all that is necessary to mark a point, and in a small scale survey the thickness of even a very hard pencil would represent several links. Fig. 294 illustrates the usual type of pricker, in the absence of

Fig. 294.

which, however, a very useful tool may be made with a halfpenny pen-holder and an embroidery needle heated in a candle and driven in eye-ways. I have one by me now whose total cost was under a penny, which I have used for years.

Parallel Rules.—Parallel rules are exceedingly useful in plotting a survey, and for traverse work they are indispensable. Those made to work upon rollers (as in Fig. 295) are the most reliable,

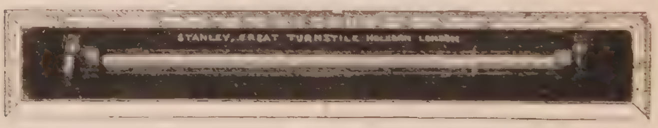


Fig. 295.

and should be from 15 to 24 in. long, brass being far preferable to ebony.

Set Squares, &c.—For setting out right angles and to facilitate plotting, vulcanite or mahogany set squares are necessary, similar

Fig. 296.

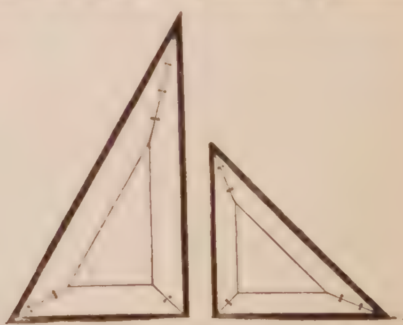


Fig. 297.

to those illustrated in Figs. 296 and 297, those in Fig. 297 being framed in mahogany and edged with ebony, but I prefer the former.

Offsets.—In plotting offsets or any of the features of a survey the greatest care is requisite. Place the edge of the scale accurately on the line, as in Fig 298, and place two weights on *a* and *b*, then gently draw the offset scale *c* along the edge of the other scale to such point as it may be required to make a lateral measurement, and prick off the length of the offset. It will be seen that a portion of a triangular field has been already plotted.

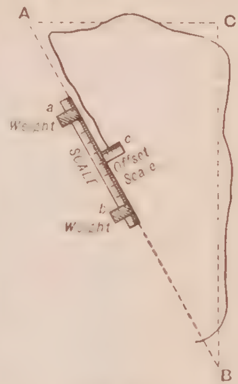


Fig. 298.

Curves.—No office should be without a box of curves, such as Fig. 299, which are made of pearwood, and are of regular radii from 1½ to 150 in.

French curves are also very useful for drawing in irregular curved figures.

Drawing Pens.—A survey should be distinguished by good draughtsmanship, equally with accuracy in execution. The various boundaries, fences, streams, buildings, &c., should be neatly drawn in ink, for which a good drawing or ruling pen is indispensable; and the survey-lines—the basis of the whole work—require to be drawn with a clear but fine line.

Fig. 299.

A good drawing pen will with care last for years. I have one of Swiss make that I had in 1862, and I am in the habit of using it at the present time. It all depends upon the way in which a pen is used and the care that is taken of it. Fig. 300 illustrates the right and wrong way of holding a drawing pen. In the former case not only do you wear the point equally, but you have perfect command over the pen, whilst in the latter you wear the points at one angle, and you cannot

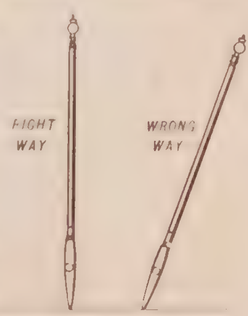


Fig. 300.

manipulate the pen with the same facility or neatness as if held vertical. The various types of drawing pens are shown in Fig. 301. A is the ordinary pen; B has a hinged nib *a* which enables it to be cleaned better than A, and also is easier to sharpen; C is a double or road pen, its chief advantage being assumed to be the possibility of drawing lines straight or curved parallel to each other at one stroke. But I am bound to confess

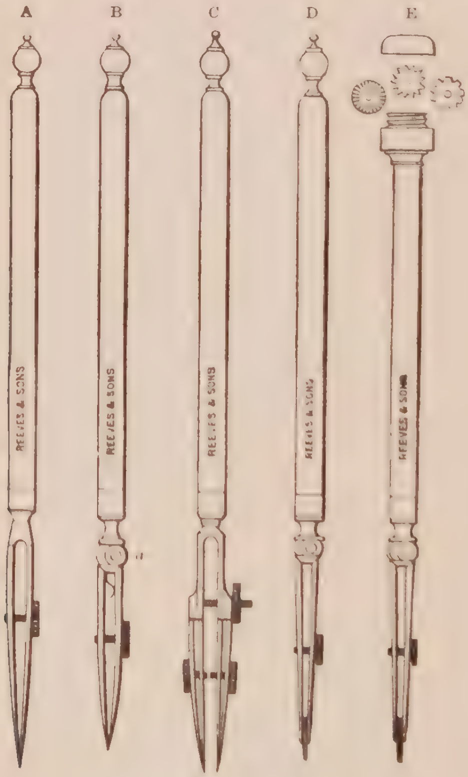


Fig. 301.

that I have only used one upon one single occasion, and found it to be not only a great nuisance but such a heavy tax upon my equanimity, and I have not tried one since. An instrument maker would strongly recommend it; I don't. D and E are dotting or wheel pens, the latter of which has at the head a small receptacle for wheels of different lengths of dot. These instru-

ments are neat as pieces of workmanship, but my advice with regard to their use is, *a la Punch*, "don't." If you are the draughtsman you should be—and there is no possible excuse why you should not—you can draw parallel and dotted lines far more neatly and effectively without such contrivances than you can with them.

Dividers.—Fig. 302 illustrates the usual form of dividers. A is the ordinary sector type, as is B, only with double joints, which for

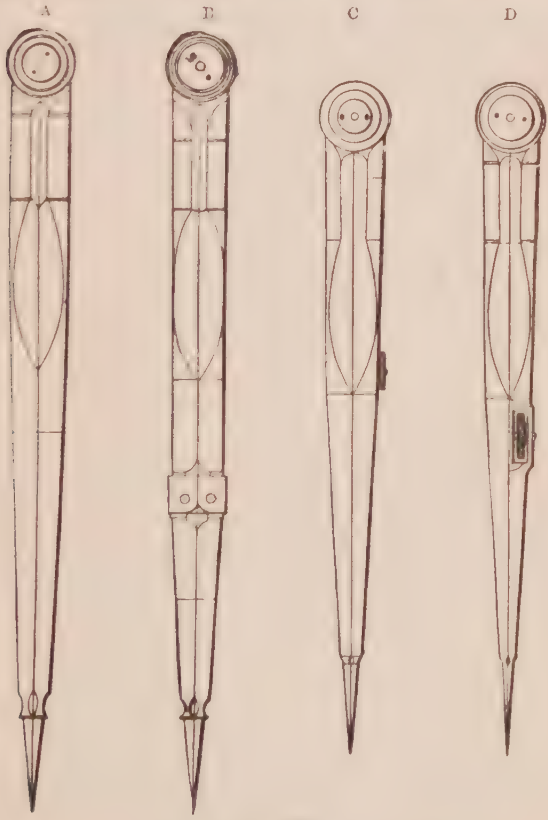


Fig. 302.

purposes required in plotting and surveying are not to be recommended, as even with the best instruments their joints in time get level. C and D are hair dividers, with outside and inside screws respectively. These instruments will be found exceedingly useful

for accurate measurements. And let me here warn the student against applying the points of the dividers upon the scale for the purpose of measuring on a plan; it is wrong and slovenly, and spoils the scales. Mark off the distance you require on paper, and apply your dividers thereto.

Spring Bows. — Needle spring-bows (Fig. 303) are indispensable for plotting a survey: the other kind make too large holes in the paper.

Drawing Instruments.—The equipment of a surveyor would be quite incomplete without a set of ordinary drawing instruments such as is shown in Fig. 304. A is the ordinary cheek compass; at *a*, the point may be removed, and in the slot may be substituted either the pencil or ink point B, or if the sweep is not sufficiently long a lengthening bow may be made to intervene.

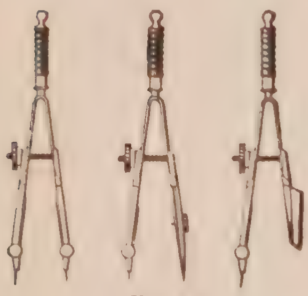


Fig. 303.

Fig. 304.

Proportional Compasses.—For enlarging and reducing plans, of which I shall have something to say presently, I now mention the proportional compass, of which Figs. 305 and 306 are illustrations —the former when closed, the latter when open for use. On the one face of the divider (as in Fig. 306), on the left of the groove is a scale of lines, whilst on the right side is one of circles, equally on the other face (see Fig. 305), on the left side of the groove is a scale of plans, and on the right one of solids.

To set the instrument, it must first be accurately closed (as in Fig. 305), so that the two legs appear but as one; the nut *c* being then unscrewed, the slider may be moved, until the line across it coincides with any required division upon any one of the scales. Now tighten the screws and the compasses are set.

To use the Proportional Compasses.—To enlarge or reduce a plan, once, twice, thrice, or up to ten times, bring the line on the slider, opposite the scale of lines to a mark represented by 2, 3, 4, 5, 6, 7, 8, 9, or 10, and at the short end you will have that much less than the other, and *vice versa*. But of this I shall say more presently.

Fig. 305.

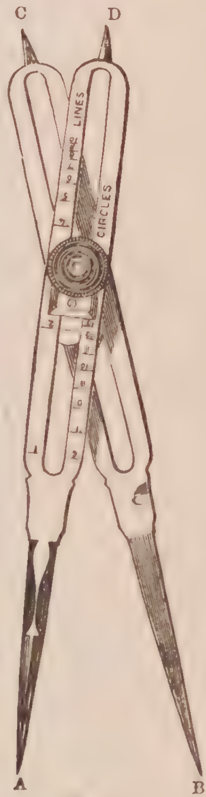


Fig. 306.

India Rubber.—This useful aid to erasure should be resorted to as little as possible, for good work and workmanship should not require to be obliterated. Yet, if it is necessary at times—and it must be of course—the best kind is Faber's improved artists' rubber; only use it gently, taking care not to damage the surface of the paper, or you will regret it when you commence putting the tints on your plan.

Indian Ink.—For all purposes of draughtsmanship the best is the only ink to be used, and the extra cost of good quality, as compared with that of inferior, is so slight as to be hardly worth discussing. Indian ink should be used quite fresh each day, and should be kept covered up. To mix it properly, place sufficient water in the saucer, and rub the ink round until it adheres to the sides. Never use either a brush or a pen for filling the drawing pen, but dip the

nib gently into the ink, and with a piece of washleather rub off the superfluous.

For mixing up indian ink or any large quantity of colour, the

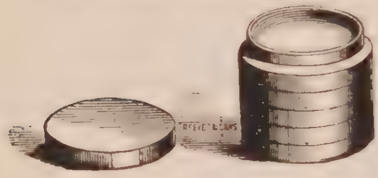


Fig. 307.

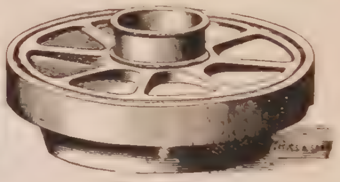


Fig. 308.

nest of saucers (Fig. 307) is most useful as fitting one on the other. They virtually keep the colour hermetically sealed. For colouring plans in great variety the round slant and basin (Fig. 308) is extremely useful, as you may have occasion to wash your brush frequently, whilst for ordinary variety of tints the ordinary straight slant (Fig. 309) is convenient.

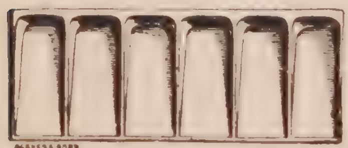


Fig. 309.

Colours.—For colouring plans, I prefer the cake to the pans, as in mixture you get a better tint without risk of foreign matter getting in, which can hardly be avoided by using a brush with the pans. Of course in the case of mixture, each colour must be separately rubbed up, and the incorporation must take place afterwards.

The following is a list of the chief colours required by the surveyor—

Brown Madder	French Blue	Raw Sienna
Burnt Sienna	Gamboge	Raw Umber
,, Umber	Hooker's Green	Scarlet Lake
Carmine	Indian Red	Sepia
Chinese White	,, Yellow	Vandyke Brown
Cobalt Blue	Indigo	Venetian Red
Crimson Lake	Neutral Tint	Vermilion
Crome Yellow	Payne's Grey	Yellow Ochre
Emerald Green	Prussian Blue	Ultramarine

Conventional Signs and Colours.—The following are some of the conventional colours used to illustrate the principal features of a survey. Fences are shown by a firm line; post and rail thus: —|—|—|—|—; walls by parallel lines; paled fences thus: — — — — — —.

Roads are tinted in light burnt sienna. Footpaths of macadam-

ised roads by a darker tint of the same colour. Pavements by neutral tint.

Buildings are variously tinted lake, whilst outbuildings are shown by light indian ink. In some cases existing buildings are shown by neutral tint or light indian ink, whilst new or proposed buildings are tinted lake. Churches or public buildings are generally delineated by some special method, such as hatching.

Water is shown by Prussian blue or ultramarine. There are various ways of doing it, the most effective being by what is termed rippling; or it may be coloured dark at the edge, and led off by a fairly dry brush, called shading. Trees are either sketched in indian

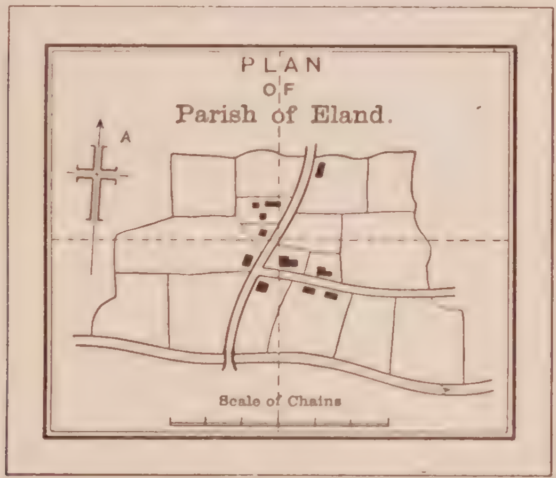


Fig. 310.

ink or are coloured. Pasture-land is tinted green, or if uncoloured is marked *Pas.*, in distinction to *Ara.* for arable land. Marsh-land and heath or gorse are shown as on page 150.

All buildings when inked in and coloured should be back-lined on the right-hand side and bottom, bearing in mind that light falls over the left shoulder at an angle of 45 deg. And here let me say that, if possible, a plan should not be coloured for at least twenty-four hours after it has been inked in, as a preventive against the ink running.

Commence Inking in from Top.—In commencing to ink in a plan, it is needless to recommend working from top to bottom, taking care to keep the lower part well covered over, so as to prevent dirt or grease getting on the paper.

Always work from Left to Right.—In all operations, field or office, it will be found most convenient to work from left to right, and in all cases the top and bottom, left and right sides of the paper, should represent north, south, west, and east.

Place Work in Centre of the Paper.—Great care should be taken so that the plan is in the centre of the paper, from the sides, leaving as much space as possible for the title, which should always be at the top, and should any of the ground be irregular in shape, as in Fig. 310 at A, it is as well to draw in the north point here, by which means the plan is more symmetrical.

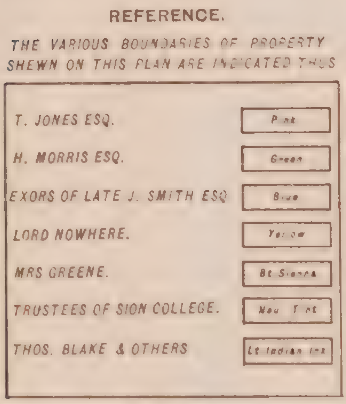


Fig. 311.

Boundaries of different Properties.—Boundaries of different property may be shown by an edging of different colours; if for one only, lake or green is most usual; but when there are a variety of owners, the boundaries are generally indicated by lake, green, blue, yellow, burnt sienna, neutral tint, light indian ink, with a schedule of colours as reference in the corner, as in Fig. 311. And where I have written the name of the colour it should be tinted in the block to correspond with the edging of the boundaries.

Paint Brushes and Pencils.—With regard to paint brushes or pencils, as they are properly called, I need hardly say that the best are the cheapest, and if taken care of will last a lifetime. To leave brushes in water, or to neglect to cleanse them after use, is unpardonable.

Precautions in Colouring.—In colouring take care to mix sufficient, never mix more than is wanted, but a less quantity makes it sometimes difficult to match. Colours should be mixed light, as if the tints are not dark enough, they can be easily strengthened by an extra coat, whereby blotched colouring is avoided. It is best to colour towards you, taking care not to go over the same place a second time if possible; the colour in parts wants to be floated towards the draughtsman. Do not take too much colour in your brush, and always have a small clean brush handy to finish off an edge. It is most convenient to have a piece of clean white blotting paper to rest the wrist on when colouring, also to take up colour that oversteps the boundary. Be very careful not to go over the edge, as it makes

a plan look very ragged. Colouring is best done by a slow and regular stroke, extra care being observed at boundaries. For shading a brush at each end of the handle is requisite, the one to put the colour on, and the other clean and slightly moistened to lead off the colour. The process is best done from left to right. Sable brushes are preferable to camel's hair.

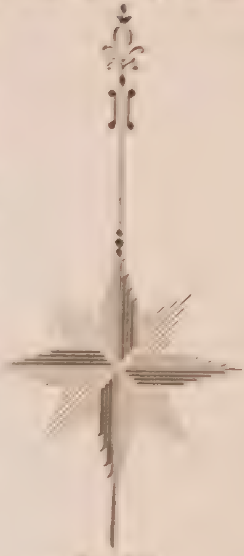


Fig. 312.

North Points.—North points are shown in various ways, some ornamental and others quite plain, of which types are here given. I have seen the plans of noblemen's and gentlemen's estates got up with such elaboration that they were almost pictures. For instance the north points were painted to represent lilies of the valley and other beautiful flowers, evidence of the artistic skill of the draughtsman; but the practical surveyor of to-day has no time or inclination to show his genius with such elegant decorations, and I recommend the adoption of a neat and simple figure, such as are illustrated

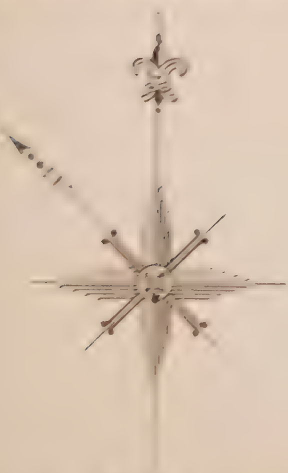


Fig. 313.

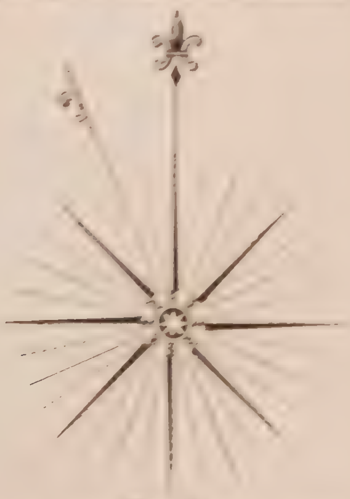


Fig. 314.

in Figs. 312, 313 and 314. In all cases the magnetic north should be shown by a dotted line.

Borders.—Every plan should have a border round it, with a margin of from 1 to $2\frac{1}{2}$ inches. A simple line is very neat for an ordinary plan, and where greater elaboration is necessary, then

Figs. 315 and 316.

Fig. 317.

either a thin line on the top and left, with a thick line bottom and right, as in Fig. 315, or as in Fig. 316, with a thick line in the midst of two fine lines. Sometimes a very fine and large plan,

Figs. 318 and 319.

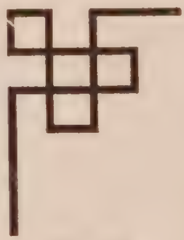


Fig. 320.

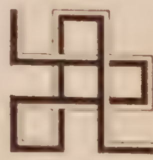


Fig. 321.

the size of which say is 16 feet square, will bear a line of neutral-tint, say three-eighths thick, and strongly back-lined in Indian ink.

Some plans are finished with ornamental corners, such as are shown in Figs. 317, 318, 319, 320, and 321, which are as simple and effective as possible; for I need hardly say that a good survey does not require much adornment, and the neater it is finished off the better will it commend itself.

Printing and Writing on Plans.—One of the last and most important things in connection with a plan is the writing, to which too much attention cannot be paid. For a plan may be perfect so far as draughtsmanship and colouring are concerned, but entirely spoilt by reason of bad writing. Here again simplicity should govern the work. There is nothing neater than block letter, either vertical or on the slant, but with a very little extra time the letters may be made effective by using tints. Now

there is a strong prevailing idea that any kind of printing will do on a plan, and a great fancy is expressed for stencil-plates. This is decidedly wrong, as the neater the writing the more effective the plan. Stencil-plates are convenient for marking sacks or the address of *voyageurs* upon those clean deal boxes one sees outside the trunk manufacturer's, but in the drawing office (except of course where work is done at so much an hour) they are out of place.

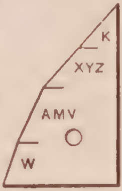


Fig. 322.

The title of a plan should be carefully set out from a centre line, and the letters, especially the large ones, pencilled faintly, for which the template, Fig. 322, will be found very useful, giving as it does the angle of the slanting portions of the various letters.

Scales.—The best kind of scales for plotting are divided into chains and tens of links on one side, and equivalent feet on the other, so that the mark of two chains would be 132 feet on the feet scale, and the same applies to the offset scale.

I do not suppose the scale-maker could offer any other explanation why 2-chain, 3-chain, and other such scales should be marked 20, 30, 40, &c. True it is they are sometimes used by engineers to plot work to 20, 30, 40 feet to an inch, but it is well to bear in mind that the scales marked 10, 20, 30, 40, 50, and 60 are really 1, 2, 3, 4, 5, and 6 chains to an inch, and the subdivisions are each ten links, and equally on the "feet" side, the 1, 2, 3, 4, &c., represent 100, 200, 300, 400, &c., feet, the greater subdivisions 10 and the lesser 5 feet each.

Enlarging and Reducing Plans.—It is often necessary to enlarge or reduce either whole or portions of surveys. For reliable purposes, the most satisfactory method is to replot the work to a larger or smaller scale from your field notes. But this may not always be possible, consequently in these days of "labour saving," we have appliances for expeditiously accomplishing these results. As this work would be incomplete without a description of the pantagraph and eidograph, I have elected to quote from an excellent authority upon the subject *—an author to whom I have already referred (*ante*, pp. 73, 74). But although I do so, it must not be inferred that I entirely approve of either instrument, against the use of which I have somewhat of a prejudice, added to which I do not consider their great cost always justifies their adoption.

Pantagraph.—"The Pantagraph (Fig. 323) consists of four rulers, A B, A C, D F, and E F, made of stout brass. The two longer rulers, A B and A C, are connected together by, and have a motion

* "Drawing and Measuring Instruments," p. 65, by J. F. Heather, M.A. Crosby Lockwood & Son, London.

round, a centre at A. The two shorter rulers are connected in like manner with each other at F, and with the longer rulers at D and E; and, being equal in length to the portions A D and A E of the longer rulers, form with them an accurate parallelogram, A D F E, in every position of the instrument. Several ivory castors support the machine parallel to the paper, and allow it to move freely over it in all directions. The arms, A B and D F, are graduated and marked $\frac{1}{2}$, $\frac{1}{3}$, &c., and have each a sliding index, which can be fixed at any of the divisions by a milled-headed clamping screw, seen in the engraving. The sliding indices have each of them a tube, adapted either to slide on a pin rising from a heavy circular weight called

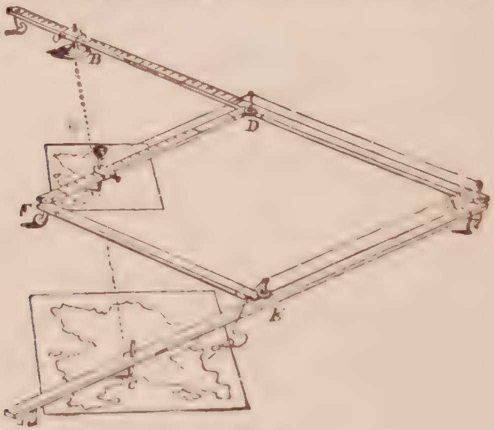


Fig. 323.

the fulcrum, or to receive a sliding holder with a pencil or pen, or a blunt tracing point, as may be required.

"When the instrument is correctly set, the tracing-point, pencil, and fulcrum will be in one straight line, as shown by the dotted line in the figure, and which may be proved by stretching a fine string over them. The motions of the tracing-point and pencil are then each compounded of two circular motions, one about the fulcrum, andthe other about the joints at the ends of the rulers upon which they are respectively placed. The radii of these motions form sides about equal angles of two similar triangles, of which the straight line B C, passing through the tracing-point, pencil, and fulcrum, forms the third side.

"The distances passed over by the tracing-point and pencil, in consequence of either of these motions, have then the same ratio, and, therefore, the distances passed over in consequence of the combination of the two motions have also the same ratio, which is that indicated by the setting of the instrument.

"Our engraving (Fig. 323) represents the pantagraph in the act of reducing a plan to a scale of half the original. For this purpose the sliding indices are first clamped at the divisions upon the arm marked ½; the tracing-point is then fixed in a socket at C, over the original drawing; the pencil is next placed in the tube of the sliding index upon the ruler D F, over the paper to receive the copy; and the fulcrum is fixed to that at B, upon the ruler A B. The machine being now ready for use, if the tracing-point at C be passed delicately and steadily over every line of the plan, a true copy, but of one-half the scale of the original, will be marked by the pencil on the paper beneath it. The fine thread represented as passing from the pencil quite round the instrument to the tracing-point at C, enables the draughtsman at the tracing-point to raise the pencil from the paper, whilst he passes the tracer from one part of the original to another, and thus to prevent false lines from being made on the copy. The pencil-holder is surmounted by a cup, into which sand or shot may be put, to press the pencil more heavily on the paper, when found necessary.

"If the object were to enlarge the drawing to double its first scale, then the tracer must be placed upon the arm D F, and the pencil at C; and if a copy were required of the same scale as the original, then, the sliding indices still remaining at the same divisions upon D F and A B, the fulcrum must take the middle station, and the pencil and tracing-point those on the exterior arms, A B and A C, of the instrument."

The Eidograph.*—"The pantagraph just described requires four supports upon the paper, and from this cause, and from its numerous joints, its action is apt to be unsteady. An instrument to avoid these defects was invented by Professor Wallace in 1821. This instrument (Fig. 324), called the eidograph, is more regular in its action than the pantagraph, as will be readily understood from the following description of its construction, by which it will be seen that there is only one point of support upon which the entire instrument moves steadily and regularly; and the joints, if we may so term them, consist of fulcrums fitting in accurately ground bearings, the motion round these fulcrums being capable of adjustment for regularity as well as accuracy. It also possesses the further advantage over the pantagraph, that it may be set with equal facility to form a reduced copy bearing any proportion whatever to the original, while the pantagraph can only be set to vary the relations between the original and the copy in the few proportions which are specifically marked upon it.

"The point of support of the eidograph is a heavy weight, H, formed exteriorly of brass and loaded internally with lead, and having three or four small needle points to keep it steady on the

* Heather's "Drawing and Measuring Instruments," p. 70.

paper. The pin, forming the fulcrum upon which the whole

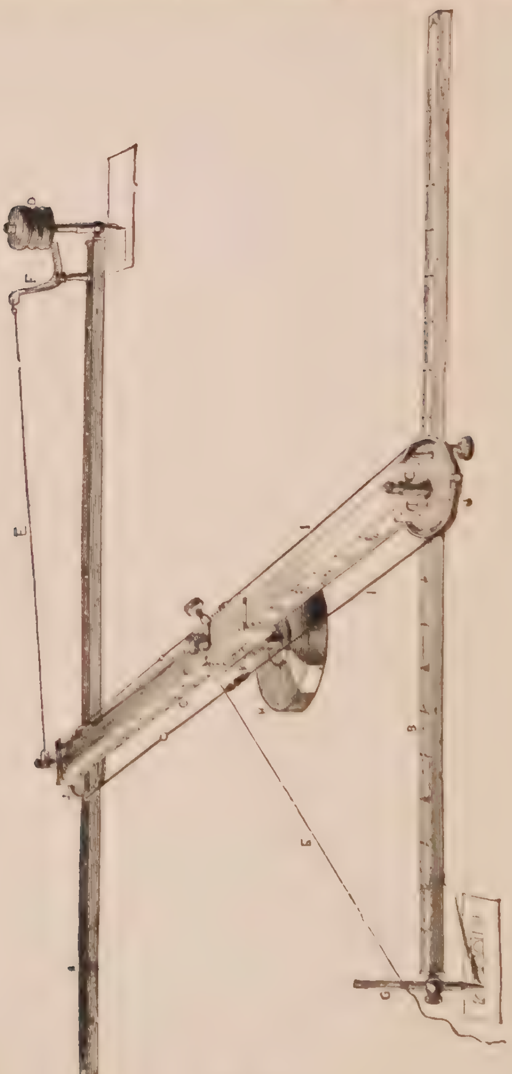


Fig. 324.

instrument moves, projects from the centre of this weight on its

upper side, and fits into a socket attached to a sliding-box, K. The fulcrums are ground to fit very accurately. The centre beam, C, of the instrument fits into and slides through the box K, and may thus be adjusted to any desired position with respect to the fulcrum, and then fixed by a clamping screw attached to the box. Deep sockets are attached to each end of the centre beam, into which are accurately fitted the centre pins of the two pulley wheels J J. These pulley wheels are made most exactly of the same diameter, and have two steel bands, I I, attached to their circumferences, so that they can move only simultaneously, and to exactly the same amount. By means of screw adjustments these bands can have their lengths regulated so as to bring the arms of the instrument into exact parallelism, and, at the same time, to bring them to such a degree of tension as shall give to the motions of the arms the required steadiness, which forms one of the advantages of the instrument over the pantagraph. The arms, A and B, of the instrument pass through sliding boxes upon the under side of the pulley wheels, these boxes, like that for the centre beam, being fitted with clamping screws, by which the arms can be fixed in any desired position. At the end of one of the arms is fixed a socket with clamping screw, to carry a tracing-point, G, and at the end of the other is a socket for a loaded pencil, D, which may be raised when required by a lever, F F, attached to a cord which passes over the centre of the instrument to the tracing-point. The centre beam C, and the arms, A B, are made of square brass tubes, divided exactly alike into two hundred equal parts, and figured so as to read one hundred each way from their centres, and the boxes through which they slide have verniers, by means of which these divisions may be subdivided into ten, so that with their help the arms and beam may be set to any reading containing not more than three places of figures. A loose leaden weight is supplied with the instrument to fit on any part of the centre beam, and keep it in even balance when set with unequal lengths of the centre beam on each side of the fulcrum.

"The pulleys, J J, being of exactly equal size, when the steel bands I I are adjusted so as to bring the arms of the instrument into exact parallelism, they will remain parallel throughout all the movements of the pulleys in their sockets, and thus will always make equal angles with the centre beam. If, then, the two arms and the centre beam be all set so that the readings of their divisions are the same, a line drawn from the end of one arm across the fulcrum to the end of the other arm will form with the beam and arms two triangles, having their sides about equal angles proportionals, and being, therefore, similar; hence any motion communicated to the end of one arm will produce a similar motion at the end of the other, so that the tracing-point being moved over

any figure whatever, an exactly similar figure will be described by the pencil.

To adjust the Eidograph, and examine its Accuracy.—"Set the indices of all three verniers to coincide with the zero divisions on the centre beam and arms, and make marks at the same time with the tracer and with the pencil; then move the pencil-point round until it comes to the mark made by the tracer, and if the tracer at the same moment comes into coincidence with the mark made by the pencil, the arms are already parallel, and the instrument consequently in adjustment; but if not, make a second mark with the tracer in its present position, and bisecting the distance between this mark and the mark made by the pencil, bring the tracer exactly to this bisection by turning the adjusting screws on the bands. The instrument being now in adjustment, if the zero division be correctly placed on the arms and beam, the pencil-point, tracer, and fulcrum will be in the same straight line, and they will still remain so when the instrument is set to give the same readings on the three scales, whatever those readings may be, if the dividing of the instrument be perfect.

"The instrument being adjusted we have next to set it so as to make the dimensions of a copy, traced by its means, bear the desired proportion to the original. It must be borne in mind that the divisions on the instrument are numbered each way from the centres of the beam and arms up to 100, and that the verniers enable us to read decimals or tenths of a division; so that if the indices of the verniers were a little beyond any divisions, as 26, and the third stroke of the verniers coincided with the divisions marked 29, the reading would be 26·3. Now suppose it were required to set the instrument so that the proportion of the copy to the original should be that of one number, a, to another number, b. Suppose x to represent the reading to which the instrument should be set, then the centre beam and arms are each divided at their fulcrums into portions whose lengths are $100 - x$ and $100 + x$ respectively, and consequently $\frac{100 - x}{100 + x} = \frac{a}{b}$, from which we find that the required reading $x = \frac{100\,(b - a)}{b + a}$; thus if the proportions are as 1 to 2, we have $x = \frac{100\,(2 - 1)}{2 + 1} = \frac{100}{3} = 33{\cdot}3$, and the instrument must be set with the third divisions of the verniers beyond the indices on the third divisions of the instrument beyond the 33rd. We have, therefore, the following simple rule: Subtract the lesser term of the proportion from the greater, and multiply it by 100 for a dividend, add together the two terms of the proportion for a divisor, and the quotient will give the reading to which the instrument is to be set.

"The following readings are thus obtained :—

Proportions.	Readings.	Proportions.	Readings.
1 : 2	33·3	2 : 3	20
1 : 3	50	2 : 5	42·9
1 : 4	60	3 : 4	14·3
1 : 5	66·7	3 : 5	25
1 : 6	71·4	4 : 5	11·1

"When the copy is to be reduced, the centre beam is to be set to the reading found, as above, on the side of the zero next to the arm carrying the pencil-point, and this arm is also to be set to the same reading on the side of its centre or zero nearest the pencil-end, while the tracer-arm is to be set with the reading furthest from the tracer. When the copy is to be enlarged, these arrangements must of course be reversed : thus 50 being the reading for the proportion 1 : 3, Fig. 325 will represent the setting to make a copy having its linear dimensions three times those of the original ; where *p* represents the position of the pencil-point, *t* that of the

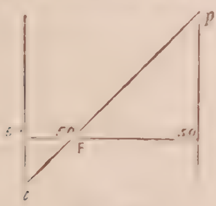


Fig. 325.

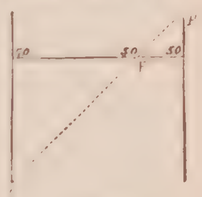


Fig. 326.

tracer, and F the place of the fulcrum. Fig. 326 represents in the same way the setting to make the linear dimensions of the copy one-third of those of the original."

Enlarging and Reducing by Squares.—Failing the replotting of the work for the purpose, the only satisfactory and accurate method of enlarging and reducing plans is by means of squares and proportional compasses. This may perhaps be best shown by the following example :—

Let Fig. 327 represent the plan of an estate which it is required to copy on a reduced scale of one-half. The copy will therefore be half the length and half the breadth, and consequently will occupy but one-fourth of the space of the original. Take a sheet of tracing paper and draw two lines at perfect right angles to each other, as O J, O 9, at the top and left of the sheet ; now very accurately and carefully divide these lines into spaces of some convenient length, say, 1½ to 2 ins., as *a*, *b*, *c*, *d*, *e*, *f*, *g*, &c., and 1, 2, 3, 4, 5, 6, &c., and draw the squares formed by the intersections in fine blue lines. Now place this piece of tracing-paper over the plan

to be enlarged or reduced and fasten it well down with drawing-pins. Then take another piece of tracing-paper and divide it into squares larger or smaller according to the proportions required: in Fig. 328 they are half the size, consequently whatever the divisions o a, o b, o 1, o 2, &c., are (Fig. 327), those in Fig. 328 will be half. Beside the plan to be reduced, on the right-hand side lay down a piece of drawing-paper, upon which shall be laid a piece of transfer-paper, and upon this is laid the sheet of smaller squares, all of

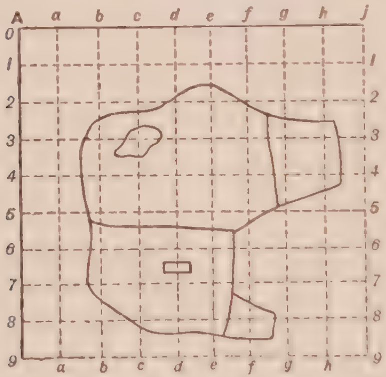


Fig. 327.

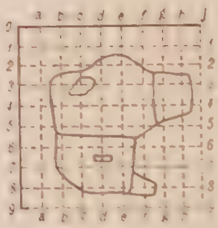


Fig. 328.

which having been firmly secured by weight or drawing-pins. In the proportional compasses fix the line across the slides to be coincident with the line opposite the 2 on the left side of the groove (Fig. 305), by which means A B is twice C D, to test which upon a line pick off any length A B, then if the points C D accurately bisect this length you have the right proportion. And as a further test, try your squares in the same way, A B being fixed at one of the subdivisions in Fig. 327, then if the sheets of squares have been accurately drawn, C D will exactly measure the length on the reduced sheet of squares. To reduce the plan, mark those points on the large squares above the fences, &c., intersect and measure vertically and horizontally the distance from the nearest intersection of the horizontal and vertical lines with the A B end of the compass, and at similar points on the small squares mark the same distances with the C D end of the compasses and make marks, then if with a fine pencil you draw the lines connecting these points, you will not only have a record of the work you have accomplished, but it will be transferred to the paper beneath.

Copying a Plan.—To copy a plan it has been recommended to place it over a sheet of clean paper, and to prick through all

the fences, buildings, &c., and then to connect the punctures by drawing the lines first in pencil and then in ink. Such a system is to be condemned: first, because it spoils both the plan and the copy by the prick marks; secondly, there is a liability of the plan becoming shifted, in which case there is no possibility of re-adjusting it; and thirdly, it takes just twice the necessary time to accomplish; added to which, there is always a liability of error.

The method I recommend is to make a neat tracing of the plan, and to place this upon transfer-paper over a sheet of drawing-paper. Then place a clean sheet of tracing-paper over the whole, and re-trace the plan, by which means you have an accurate record of how much of the work you have accomplished, and no injury is done to the paper upon which the plan is to be copied.

General Hints.—In plotting a survey the following hints may be useful:—

1. Dust your table, and well cover that part of the paper upon which you are not working.

2. Do not wear your watch in your waistcoat pocket.

3. Do not have an inkstand or your colour pans on the same table.

4. Always clean your scales, protractor, set-squares, straight-edge, &c., before use.

5. Rule in your survey lines in lake or carmine before you commence to plot your details.

6. Always use fresh ink every day, and do not colour over work recently inked in.

7. Before commencing to plot, draw a scale on the paper, and also a north point.

8. Do not make calculations upon slips of paper, but always have a foolscap scribbling-book at hand, in which enter all your calculations and the dates upon which they are made.

9. Keep a separate field-book for each survey, and be careful to enter the dates of each day's work.

CHAPTER XIII.

LAND QUANTITIES.

The surveyor has not performed all his duties when he has plotted and finished his plan, for a matter of the greatest importance, next to an accurate survey, is to have a true record of the areas of the various properties shown upon the plan.

There are so many works which deal more or less exhaustively with the subject of computation of areas and quantities, that I do not propose to do more than briefly consider the various methods which may be adopted for the purpose, and to endeavour to apply them practically for the information of those who may not have had an opportunity of perusing such books, or to whom possibly the meaning of all that was contained therein has not been made sufficiently clear.

To commence, then, it may be useful if I give the following table of superficial measure :—

An Acre	=	4 Roods,	a Rood	=	40 Perches.
,,	=	160 Perches	,,	=	1,210 Yards.
,,	=	4,840 Yards	,,	=	10,890 Feet.
,,	=	43,560 Feet	,,	=	1,568,160 Inches.
,,	=	6,272,640 Inches			

		SQUARE.		SQUARE.		SQUARE.
A Perch	=	30¼ Yards,	a Yard	=		9 Feet.
,,	=	272¼ Feet	,,	=		1,296 Inches.
,,	=	39,204 Inches,	1 Foot	=		144 Inches.

10 Square Chains = 1 Acre.

1 Mile a chain wide = 8 Acres.

1 square mile	=	640 Acres.
	=	3,097,600 Square Yards.
	=	27,878,400 ,, Feet.

To convert Acres into Square Miles multiply by ·0015625.
To convert Square Yards into Square Miles multiply by ·000000323.

Keep forcibly in mind that a strip of land 10 chains long and 1 chain wide is 1 acre; that 10 chains = 1 furlong; that there are

8 furlongs to a mile; and consequently if 10 sq. chains = 1 acre, then 8 furlongs, 1 chain wide, will give the result of 8 acres per lineal mile.

Suppose we have a piece of ground which measures $23\frac{1}{4}$ chains long and $6\frac{1}{2}$ chains wide, then

$$23{\cdot}25 \times 6{\cdot}5 = 151{\cdot}125 \text{ square chains.}$$

Now if we divide 151·125 by 10 we get 15·1125 acres, the decimal part of which should be multipl.ed by 4 to reduce it to roods, and the decimal part of the remainder by 40 to reduce it to perches thus—

$$\overset{\text{A.}}{15{\cdot}1125} = \overset{\text{A.}}{15}\ \ \overset{\text{R.}}{0}\ \ \overset{\text{P.}}{1{\cdot}80}.$$

Averages in Fence Lines.—One of the first things necessary to be perfectly understood is, how to determine the averages of uneven fences or boundaries. I mean that it is simple enough with a piece of ground whose boundaries form a regular figure, such as a square or rectangle; but in practice this is seldom if ever the case, and the fences or boundaries being uneven and irregular, it is necessary to adjust them so that the inequalities may be accounted for. Fig. 329 is a simple illustration of what I mean.

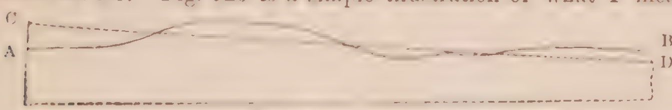


Fig. 329.

The boundary fence A B curves in and out, so that it is necessary to establish a mean line that will represent fairly the average. To do this we resort to what is termed a "give-and-take line," as C D; by which those portions of the ground on the top side of C D are ignored, as their area is considered to be equivalent to that of those portions below the line, which are really out of the property.

The same principles apply in the case of a slanting boundary, whence it is necessary to measure to get the mean length between two parallel boundaries, as in Fig. 330. Here, on the left of the property, is a fence running diagonally, whose length on the top side is 6 chains, and on the bottom side 8 chains. To get the mean length of course we can say $\frac{6 + 8}{2} = 7$ chains, but in practice a little judgment will enable one to arrive at a fairly accurate result.

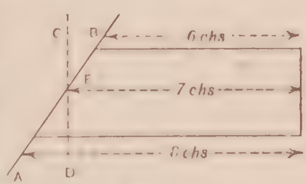


Fig. 330.

By Triangles.—The most simple, and indeed most satisfactory, method of computing areas is by means of triangles. Thus, if upon the plan to be measured a sheet of tracing-paper is spread and securely fastened, then, with a fine pencil, let the whole area be divided into triangles, each of which (beginning at the top) should be consecutively numbered, and at the boundaries let the indentations of the fence be carefully treated on the give-and-take principle. This being done, lines perpendicular to the longest sides of each triangle should be dotted, and these, together with the longest sides, should now be accurately measured, and the dimensions scheduled as in the following example, Fig. 331. Here we have

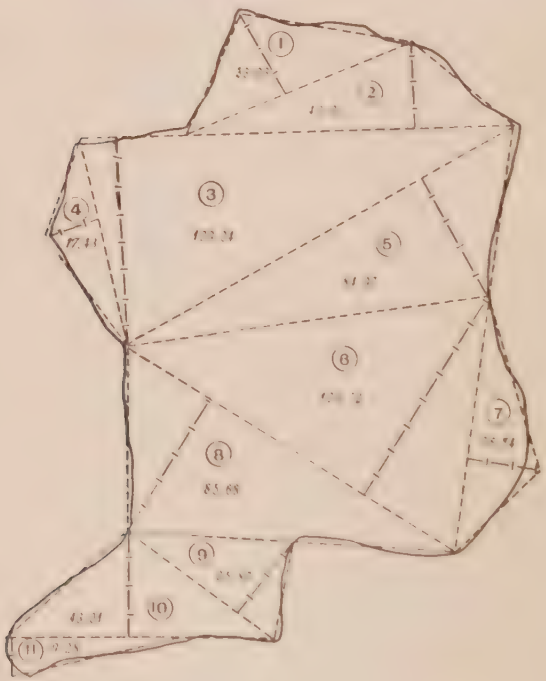


Fig. 331.

a property—the internal fences being purposely left out—the area of which it is necessary to compute. It will be seen that it has been divided into eleven triangles, the sides of some of which have been arranged so as to "give and take" the inequalities of the boundaries. The dotted lines show the triangulation, whilst

the perpendiculars are delineated by a dot and cross-stroke. The following is the schedule :—

Triangle No.	1.	9·05 × 3·65 =	33·03	sq. chains.
,,	2.	12·00 × 3·50 =	42·00	,,
,,	3.	16·05 × 8·04 =	129·04	,,
,,	4.	8·30 × 2·10 =	17·43	,,
,,	5.	16·50 × 5·15 =	84·97	,,
,,	6.	14·40 × 8·80 =	126·72	,,
,,	7.	9·62 × 2·78 =	26·74	,,
,,	8.	14·40 × 5·95 =	85·68	,,
,,	9.	6·90 × 3·75 =	25·87	,,
,,	10.	9·82 × 4·38 =	43·01	,,
,,	11.	5·80 × 1·60 =	9·28	,,

Divide by 2 and by 10)623·77

31·188 acres.
4

0·752
40

30·080

A. R. P.
Area = 31 0 30

It is always better to take the measurements in chains and decimals, to multiply them together, and divide the sum of the whole triangles by 2, to get the area.

Another example, Fig. 332, will serve a double purpose, viz., how the area may be determined as readily upon the ground, and without plotting, as from a plan. The figure is somewhat in the form of a boot, and by laying out a large triangle A B E, and another D C B, we are able by triangles to get the area of the greater portion of the field without much trouble. Upon the line A E of the

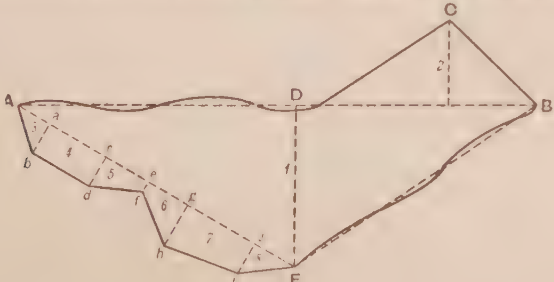


Fig. 332.

larger triangle set up ordinates *a b*, *c d*, *e f*, *g h*, and *j k*. Then the area of each space 3 to 8 may be obtained as follows :—

3. $A\,a = 1{\cdot}40$
$\times\, a\,b = 1{\cdot}20$
$1{\cdot}68$ area.

4. $a\,b = 1{\cdot}20$
$+\, c\,d = 1{\cdot}30$
$2{\cdot}50$
$\times\, a\,c = 2{\cdot}50$
$6{\cdot}25$ area.

5. $c\,d = 1{\cdot}30$
$+\, e\,f = 0{\cdot}40$
$1{\cdot}70$
$\times\, c\,e = 1{\cdot}83$
$3{\cdot}111$ area.

6 $e\,f = 0{\cdot}40$
$+\, g\,h = 1{\cdot}80$
$2{\cdot}20$
$\times\, e\,g = 1{\cdot}60$
$3{\cdot}52$ area.

7. $g\,h = 1{\cdot}80$
$+\, g\,k = 1{\cdot}40$
$3{\cdot}20$
$\times\, g\,j = 2{\cdot}95$
$9{\cdot}44$ area.

8. $j\,E = 1{\cdot}40$
$\times\, j\,E = 1{\cdot}75$
$2{\cdot}45$ area.

All the foregoing are double areas, 3 and 8 being triangles, the sides A a and j E are respectively multiplied by $a\,b$ and $j\,k$. The areas 4, 5, 6, and 7 have their two ends *added* together, and the sum multiplied by the distance apart. They may be tabulated as follows:—

No. 3 = 1·68
" 4 = 6·25
" 5 = 3·111
" 6 = 3·52
" 7 = 9·44
" 8 = 2·45

26·451 sq. chains.
Add double area of No. 1 triangle = 87·120 "
" " 2 " = 25·428 "

Divide by 2 and by 10)138·999

6·949 acres area.
4

3·7996
40

31·9840

Total area, 6 A. 3 R. 32 P.

The double area of No. 1 triangle is $14{\cdot}40 \times 6{\cdot}05 = 87{\cdot}12$; and No. 2 is $8{\cdot}15 \times 3{\cdot}12 = 25{\cdot}428$.

Ascertaining Areas on Ground.—In Fig. 333 is illustrated Simpson's method of computing the area of an irregular piece of ground, either with or without plotting. In this case the line A B should be measured as near as possible in the middle of the plot, and marks should be left in the ground at the end of each chain, and lines at right angles should be drawn through these points, which should be measured.

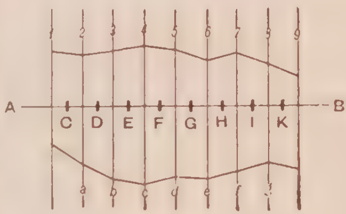


Fig. 333.

The following rule applies in this case:—

1st. The first and last lengths should be added together separately.

2nd. Now add the 2nd, 4th, 6th, and 8th lengths together, and multiply the result by 4.

3rd. Take 3rd, 5th, and 7th lengths, and multiply their sum by 2.

4th. Collect all these sums together, multiply by the common distance, or 100 links, and one-third of the product will be the area.

Example:—

A = 300	*a* 2 = 350	*b* 3 = 400
B = 300	*c* 4 = 450	*d* 5 = 430
——	*e* 6 = 400	*f* 7 = 400
600	*g* 8 = 350	——
6,200	——	1230
2,460	1550	2
——	4	——
9,260	——	2,460
100	6200	
——		
3)926,000		
——		

308,666 = 3 A. 0 R. 0 C. 13 P. 541 L.—*Ans.*

Another and simpler way, but at the same time somewhat approximate, is to mark every half-chain, so that an imaginary line through C, D, E, F, G, H, I, K, will give a mean length of the strips 1 2, 2 3, 3 4, 4 5, 5 6, 6 7, 7 8, 8 9. If these lengths are

added together and the result multiplied by 100, we shall have the area, as follows:—

Example	C =	325
,,	D =	375
,,	E =	425
,,	F =	444
,,	G =	415
,,	H =	403
,,	I =	375
,,	K =	325
		3087
		100

308,700 = 3 A. 0 R. 0 C. 13 P. 575 L.—*Ans.*

The slight discordance between this result and that gained in the same example above, shows the necessity of adhering to the previous and more accurate method, although it must be noted that neither of these is so simple or so satisfactory as the method of computing areas by means of triangles.

Computation Scale.—This last example serves as an excellent introduction to the computation scale, for the principles involved are precisely the same. For this, it is customary to prepare a piece of tracing-paper with parallel lines a certain distance apart, drawn in blue. This distance between the lines is so arranged that a scale divided especially for the purpose, and moved from left to right between any two lines, shall record the area of the strip according to the length traversed. Thus, as a simple illustration, suppose we have spans of one quarter of an inch, and use a scale of four chains to an inch, the span would thus represent one chain. If we apply the scale to the left end of the span, and read ten chains on our scale, we shall have obtained an area of one acre; and supposing we were to measure the whole length of a 12-inch scale, which would give 48 chains, then we should record 4 acres and $\frac{8}{10}$ths of another acre, or 4 A. 3 R. 08 P.

Now, what is done is to place the sheet of tracing-paper upon the plan to be computed and carefully fasten it down, taking care that one of the parallel lines cuts the most extreme point of the top of the plan; then, as each span will pass through the boundaries of the property, so may the area be computed.

Plate 4 (p. 280) is a practical illustration of the *modus operandi* of ascertaining the acreage by means of the computing scale. It represents a plan of an estate, drawn to a scale of 4 chains to an inch, over which is placed (and fastened down with drawing-pins) a sheet of tracing-paper, upon which have been carefully drawn blue lines

¼ inch apart. For convenience of illustration these parallel lines are shown dotted. It will be seen that the line A B impinges on to the extreme north of the plan, and the vertical lines A and B have been judged to equalise the whole area of that portion of the property which lies between the lines A B and C D. That portion which is hatched is excluded from computation as being equal in area to the ground traversed by the line A B and which is exterior to the actual boundary. The same applies to the points at C D, E F, G H, I J, K L, &c.

The computing scale, which is fully illustrated in the plate, is shown in position upon the plan, having traversed from the line A B to J′ K′. It consists of a boxwood scale—in this case—1 ft. 7 in. long, 1¼ in. wide, and ¼ in. thick. It has an undercut groove along its centre in which travels the tongue A A (Fig. 334), to

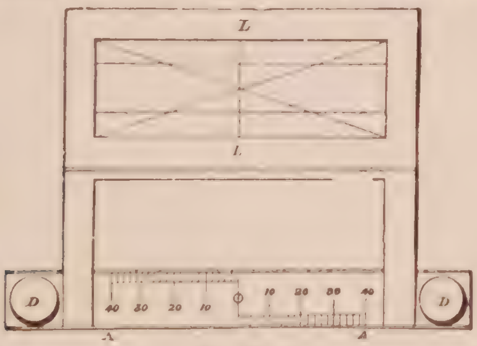


Fig. 334.

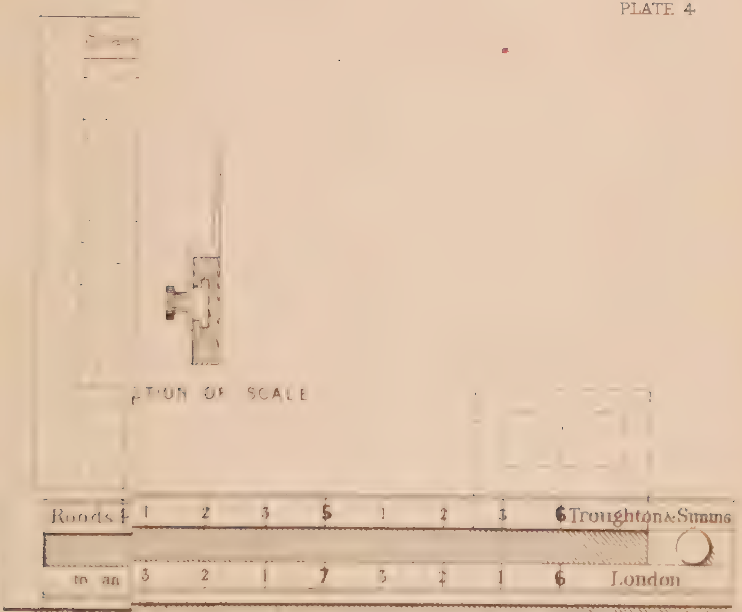
which is attached, by means of the screw handles D D, the frame C C, which passes over the side of the rule and lies flat upon the paper on which the rule is placed when in use. The handles D D enable the tongue and attached frame to be moved with facility in the groove. The scale on the upper and lower side of the groove is divided into six equal parts of 2½ in. each, representing 6 acres (10 chains a chain wide being an acre, will to the scale of 4 chains to 1 in. be 2½ in. by ¼ in.), and each of which are subdivided into 4 parts representing roods. The scale as illustrated is divided into acres and roods from 1 to 6, reading from left to right, and from 6 to 12 from right to left, so that when the tongue and frame have traversed the full length of the scale to 6 acres it may be moved back and will record acres, &c., from 6 to 12. Upon the tongue is an index drawn across its centre, and on each side of this index a distance equal to one of the subdivisions on the rule is divided into 40 equal parts to represent perches. These divisions

are placed, those on the left side of the index to read with the divisions of the scale on the upper side of the groove, and those on the right of the index to read with the divisions on the under side of the groove.

In some scales the frame carries a piece of thin horn on which are ruled two lines parallel to the rule, at a distance apart which represents a chain, and the centre of this enclosure being determined by the intersections of its diagonals, a line L L, called the index line, is drawn through this centre at right angles to the parallel lines, and in the same straight line with the index on the brass tongue. But many scales are made with small holes pierced at L L, through which a piece of fine wire or thread is passed and held tightly in position by means of screws. The scale shown in the plate is arranged on this principle, and is shown to have the index wire or line to have passed from left to right, from zero to 2 acres and past 2 roods, whilst the index on the tongue records on the left side 21 perches (of course reading from right to left) so that the area of the space between the lines from J to K′ is 2 A. 2 R. 21 P. The dotted outline of the index frame on the left shows the position at the commencement, whilst that on the right shows its position at the end of the scale, so that the arm, having only traversed about one-half the length of the scale from J′ to K′, the scale must be carefully taken up and adjusted so that the index line cuts the "give-and-take" line of the next span from L′ to M′, and so on until the full length of the scale has been run. Referring to the plate, it will be seen that the progress of the index frame from A to B was 0 A. 1 R. 24 P., and having been moved to C it reads 1 A. 1 R. 0 P. at D, 2 A. 2 R. 1 P. at F, 3 A. 3 R. 26 P. at H, 5 A. 1. R. 18 P. at J, and we arrive at the extent of the scale before we can reach L, consequently when the index is at 6 A. 0 R. 0 P. as at *a*, we mark the point with a fine pencil line.

Here I would pause to say that in this, as in all surveying operations, I strongly advocate working *always* from left to right, and consequently I should prefer the lower portion of the scale to be divided from 6 to 12, working left to right, instead of the way in which it is shown. It will be seen that I have used it in this case, as I advocate, instead of retracing our steps from 6 to 12, to do which I have added the readings on the upper scale to 6, 12, 18, 24, and 30 acres as the case has been, so that from *a* to N the scale recorded 0 A. 3 R. 21 P., therefore 6 A. + 0 A. 3 R. 21 P. = 6 A. 3 R. 21 P., and so on until *b*, *c*, *d*, and *e*. Thus, in the position of the scale at J′ K′ we have had *five* changes of *six* acres, and a length from *e* to K′ of 2 A. 2 R. 21 P., or a total area from A B to J′ K′ of 32 A. 2 R. 21 P.

Various Kinds of Computing Scales.—There are numerous types of computing scales, some of a universal character, and



Half full Size

Crosby Lockwood & Son 7, Stationers Hall Court London

others so constructed that instead of the frame working upon a tongue, the groove is made to receive strips of very thin box-wood, upon which are divided scales of from 1 to 6 chains to an inch, and the various Ordnance scales. Mr. Stanley, of Great Turnstile, has brought out this scale, which, together with six or eight strips, is made to fit into a case, the whole cost being £2 18s. 6d., and supplied with each set are specially-prepared sheets of divided paper.

Areas by different Scales to Plan.—The scale illustrated in the plate is of so simple and reliable a character that it commends itself; and whilst it is desirable, in an office where computation on a large scale is carried on, to have computing scales of the various scales in vogue, yet it is quite possible to arrive at an accurate estimate of the area of property drawn to a different scale from that of the computer. For instance, suppose we have a plan 5 chains to an inch, the area of which it is desired to ascertain, but our computing scale is 3 chains to an inch. As an example, we will assume that the operation of computation gives a result of 6 A. 2 R. 0 P. with the scale. Now, as 5 chains to an inch is much smaller than 3 chains, then the area will necessarily be greater, so that if we treat it as a rule-of-three sum we shall get the correct result. In examinations, I regret to say, this question has been a source of trouble and embarrassment to many students, who, even if they are happy in thinking of the proportion, quite forget that it will not be as three to five; but, as they are dealing with areas, it is as the square of three is to the square of five, so is the known area to that required. So that, having the area with the 3 chain scale of 6 A. 2 R. 0 P., we proceed as follows: $3^2 : 5^2 :: 6$ A. 2 R. 0 P. : 18 A. 0 R. 8 P. 26 YDS. 8 FT. = area of the plan drawn to a scale of 5 chains to an inch.

The cost of a computing scale similar to the one illustrated is £1 5s.

Planimeter.—There is another method of ascertaining the areas of a plan by what is known as the planimeter, invented by J. Amsler, Professor of Mathematics at Schaffhausen, and manufactured by Messrs. Elliott Brothers, of St. Martin's Lane, the cost of which is £3 3s. But it is a very delicate instrument, and the slightest dirt or rust will throw it out of gear. "It consists essentially of two arms jointed together, so as to move with perfect freedom in one plane, and a wheel which is attached to one of the arms, and turning on this arm as an axis, records by its revolutions the area of the figure traced out by a point on the arms to which it is attached, while a point on the other arm is made a fixed centre, about which the instrument revolves." For a full description of

its various parts, and of the method of using it, I cannot do better than refer the reader to Heather's "Drawing and Measuring Instruments," p. 80.* Like all instruments the object of which is to save labour, the planimeter, from the very delicacy of its construction, has to be used with the greatest care; and for ordinary practice it is hardly advisable to adopt it, on account of its great liability to injury. For myself, I cannot help saying that I much prefer to take off the quantities of land either by triangles or with a computing-scale.

* Crosby Lockwood & Son, London.

APPENDIX.

TABLES FOR USE IN THE FIELD.

NATURAL SINES, TANGENTS, AND SECANTS, WITH THEIR COMPLEMENTS.

The subjoined tables of sines, tangents, secants, &c., will be found to be complete in themselves. But, in order that the student may clearly understand their construction, he may be referred to Chapter IV., page 110, where the formulæ for a right-angled triangle are given.

A right-angled triangle may be set out, either in the field or on a drawing table, by use of the proportions 3, 4, and 5 (Fig. 335), for the base, perpendicular, and hypotenuse, respectively. Consequently, using the above formulæ to find the sine, we have to divide B C by A B, which means—

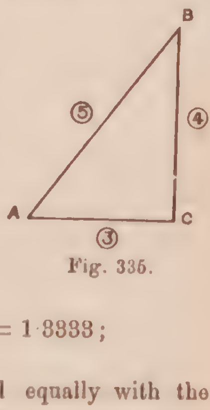


Fig. 335.

$$\text{Sine } A = \frac{4}{5} = \cdot 800000\,;\ \ \tan A = \frac{4}{3} = 1 \cdot 3333\,;$$

$$\text{and Sec } A = \frac{5}{3} = 1 \cdot 6666 \quad . \quad . \quad . \quad \text{and equally with the}$$

complements of this angle.

On referring to the Tables of Natural Sines it will be seen that the nearest approach to 0·800000 is 0·7998593 for 53° 07′, and 0·8000338 for 53° 08′, so that if the equation were worked out to a nicety, a more accurate result would be attained.

Again, our calculation shows the tangent to be 1·33333, and by reference to the Tables we see that 1·3326822 represents 53° 07′, and 1·3334900, 53° 08′. And as regards the secant, in the same way 1·6661458 represents 53° 07′, and 1·6667920 = 53° 08′. In like manner, each function of the triangle may be elucidated.

0 Deg.				1 Deg.				2 Deg.			
	Sine	Cosine			Sine	Cosine			Sine	Cosine	
0	0000000	1.0000000	60	0	0174524	[illegible]	60	0	0348995	[illegible]	60
1	0002909	1.0000000	59	1	0177432	[illegible]	59	1	0351902	[illegible]	59
2	0005818	9999998	58	2	0180341	[illegible]	58	2	0354809	[illegible]	58
3	0008727	[illegible]	57	3	0183249	[illegible]	57	3	0357716	[illegible]	57
4	0011636	9999993	56	4	0186158	[illegible]	56	4	0360623	[illegible]	56
5	0014544	9999989	55	5	0189066	[illegible]	55	5	0363530	[illegible]	55
6	0017453	9999985	54	6	0191974	[illegible]	54	6	0366437	[illegible]	54
7	0020362	9999979	53	7	0194883	[illegible]	53	7	0369344	[illegible]	53
8	0023271	9999973	52	8	0197791	[illegible]	52	8	0372251	[illegible]	52
9	0026180	9999966	51	9	0200699	[illegible]	51	9	0375158	[illegible]	51
10	0029089	9999958	50	10	0203608	9997927	50	10	0378065	[illegible]	50
11	0031998	9999949	49	11	0206516	9997867	49	11	0380971	[illegible]	49
12	0034907	9999939	48	12	0209424	9997807	48	12	0383878	[illegible]	48
13	0037815	9999928	47	13	0212332	9997745	47	13	0386785	[illegible]	47
14	0040724	9999917	46	14	[illegible]	9997683	46	14	0389692	[illegible]	46
15	0043633	9999905	45	15	0218149	9997620	45	15	0392598	[illegible]	45
16	0046542	9999892	44	16	0221057	9997556	44	16	0395505	[illegible]	44
17	0049451	9999878	43	17	0223965	9997492	43	17	[illegible]	[illegible]	43
18	0052360	9999863	42	18	0226873	9997426	42	18	[illegible]	[illegible]	42
19	0055268	9999847	41	19	0229781	9997360	41	19	0404224	[illegible]	41
20	0058177	9999831	40	20	0232690	9997292	40	20	0407131	[illegible]	40
21	0061086	9999813	39	21	0235598	9997224	39	21	0410037	[illegible]	39
22	0063995	9999795	38	22	0238506	[illegible]	38	22	0412944	[illegible]	38
23	0066904	9999776	37	23	[illegible]	[illegible]	37	23	0415850	[illegible]	37
24	0069813	9999756	36	24	0244322	9997015	36	24	0418757	[illegible]	36
25	0072721	9999736	35	25	0247230	9996943	35	25	0421663	[illegible]	35
26	0075630	9999714	34	26	0250138	9996871	34	26	0424569	[illegible]	34
27	0078539	9999692	33	27	[illegible]	9996798	33	27	0427475	[illegible]	33
28	0081448	9999668	32	28	0255954	9996724	32	28	0430382	[illegible]	32
29	0084357	9999644	31	29	0258862	[illegible]	31	29	0433288	[illegible]	31
30	0087265	9999619	30	30	0261769	[illegible]	30	30	0436194	[illegible]	30
31	0090174	9999593	29	31	0264677	[illegible]	29	31	0439100	[illegible]	29
32	0093083	9999567	28	32	0267585	[illegible]	28	32	[illegible]	[illegible]	28
33	0095992	9999539	27	33	0270493	[illegible]	27	33	[illegible]	[illegible]	27
34	0098900	9999511	26	34	0273401	[illegible]	26	34	[illegible]	[illegible]	26
35	0101809	9999482	25	35	0276309	[illegible]	25	35	[illegible]	[illegible]	25
36	0104718	9999452	24	36	0279216	[illegible]	24	36	[illegible]	[illegible]	24
37	0107627	9999421	23	37	[illegible]	[illegible]	23	37	[illegible]	[illegible]	23
38	0110535	9999389	22	38	0285032	[illegible]	22	38	[illegible]	[illegible]	22
39	0113444	9999357	21	39	0287940	[illegible]	21	39	[illegible]	[illegible]	21
40	0116353	9999323	20	40	0290847	[illegible]	20	40	[illegible]	[illegible]	20
41	0119261	9999289	19	41	0293755	[illegible]	19	41	[illegible]	[illegible]	19
42	0122170	9999254	18	42	[illegible]	[illegible]	18	42	[illegible]	[illegible]	18
43	0125079	9999218	17	43	[illegible]	[illegible]	17	43	[illegible]	[illegible]	17
44	0127987	9999181	16	44	[illegible]	[illegible]	16	44	[illegible]	[illegible]	16
45	0130896	9999143	15	45	0305385	[illegible]	15	45	[illegible]	[illegible]	15
46	0133805	9999105	14	46	0308293	9995247	14	46	[illegible]	[illegible]	14
47	0136713	9999065	13	47	0311200	9995157	13	47	[illegible]	[illegible]	13
48	0139622	9999025	12	48	0314108	9995066	12	48	[illegible]	[illegible]	12
49	0142530	[illegible]	11	49	0317015	9994974	11	49	[illegible]	[illegible]	11
50	0145439	[illegible]	10	50	0319922	9994881	10	50	[illegible]	[illegible]	10
51	0148348	9998900	9	51	0322830	9994788	9	51	0497214	[illegible]	9
52	0151256	9998850	8	52	0325737	9994693	8	52	0500119	[illegible]	8
53	0154165	9998812	7	53	0328644	9994598	7	53	0503024	[illegible]	7
54	0157073	9998766	6	54	0331552	9994502	6	54	0505929	[illegible]	6
55	0159982	9998720	5	55	0334459	9994405	5	55	0508835	[illegible]	5
56	0162890	9998673	4	56	0337366	9994308	4	56	0511740	[illegible]	4
57	0165799	9998625	3	57	0340274	9994209	3	57	0514645	[illegible]	3
58	0168707	9998577	2	58	0343181	[illegible]	2	58	0517550	[illegible]	2
59	0171616	9998527	1	59	0346088	9994009	1	59	0520455	[illegible]	1
60	0174524	9998477	0	60	0348995	9993908	0	60	0523360	[illegible]	0
	Cosine	Sine			Cosine	Sine			Cosine	Sine	
		Deg. 89.				Deg. 88				Deg. 87.	

3 Deg.

	Sine	Cosine	
0	[illegible]	[illegible]	60
1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58
3	[illegible]	[illegible]	57
4	[illegible]	[illegible]	56
5	[illegible]	[illegible]	55
6	[illegible]	[illegible]	54
7	[illegible]	[illegible]	53
8	[illegible]	[illegible]	52
9	[illegible]	[illegible]	51
10	[illegible]	[illegible]	50
11	0555311	9984570	49
12	0558215	9984408	48
13	0561119	9984245	47
14	0564024	9984081	46
15	0566928	9983917	45
16	0569832	9983751	44
17	0572736	9983585	43
18	0575640	9983418	42
19	0578544	9983250	41
20	0581448	9983082	40
21	0584352	9982912	39
22	0587256	9982742	38
23	0590160	9982570	37
24	0593064	9982398	36
25	0595967	9982225	35
26	0598871	9982052	34
27	0601775	9981877	33
28	0604678	9981701	32
29	0607582	9981525	31
30	0610485	9981348	30
31	0613389	9981170	29
32	0616292	9980991	28
33	0619196	9980811	27
34	0622099	9980631	26
35	0625002	9980450	25
36	0627905	9980267	24
37	[illegible]	[illegible]	23
38	0633711	9979900	22
39	0636614	9979716	21
40	0639517	9979530	20
41	0642420	9979343	19
42	0645323	9979156	18
43	0648226	9978968	17
44	0651129	9978779	16
45	0654031	9978589	15
46	0656934	9978399	14
47	0659836	9978207	13
48	0662739	9978015	12
49	0665641	9977821	11
50	0668544	9977627	10
51	0671446	9977133	9
52	0674349	9977237	8
53	0677251	9977040	7
54	0680153	9976843	6
55	0683055	9976645	5
56	0685957	9976445	4
57	0688859	9976245	3
58	0691761	9976045	2
59	0694663	9975843	1
60	0697565	9975641	0
	Cosine	Sine	

Deg. 86.

4 Deg.

	Sine	Cosine	
0	0697565	9975641	60
1	0700467	9975437	59
2	0703368	9975233	58
3	0706270	9975028	57
4	0709171	9974822	56
5	0712073	9974615	55
6	0714974	9974408	54
7	0717876	9974199	53
8	0720777	9973990	52
9	0723678	9973780	51
10	0726580	9973569	50
11	0729481	9973357	49
12	0732382	9973145	48
13	0735283	9972931	47
14	0738184	9972717	46
15	0741085	9972502	45
16	0743986	9972286	44
17	0746887	9972069	43
18	0749787	9971851	42
19	0752688	9971633	41
20	0755589	9971413	40
21	0758489	9971193	39
22	0761390	9970972	38
23	0764290	9970750	37
24	0767190	9970528	36
25	0770091	9970304	35
26	0772991	9970080	34
27	0775891	9969854	33
28	[illegible]	[illegible]	32
29	0781691	9969401	31
30	0784591	9969173	30
31	0787491	9968945	29
32	0790391	9968715	28
33	0793290	9968485	27
34	0796190	9968254	26
35	0799090	9968022	25
36	0801989	[illegible]	24
37	[illegible]	[illegible]	23
38	0807788	[illegible]	22
39	0810687	[illegible]	21
40	0813587	[illegible]	20
41	0816486	[illegible]	19
42	0819385	[illegible]	18
43	0822284	[illegible]	17
44	0825183	[illegible]	16
45	0828082	[illegible]	15
46	0830981	[illegible]	14
47	0833880	[illegible]	13
48	0836778	[illegible]	12
49	0839677	[illegible]	11
50	0842576	[illegible]	10
51	0845474	[illegible]	9
52	0848373	[illegible]	8
53	0851271	[illegible]	7
54	0854169	[illegible]	6
55	0857067	[illegible]	5
56	[illegible]	[illegible]	4
57	0862864	[illegible]	3
58	0865762	[illegible]	2
59	0868660	[illegible]	1
60	0871557	[illegible]	0
	Cosine	Sine	

Deg. 85.

5 Deg.

	Sine	Cosine	
0	0871557	9961947	60
1	0874455	9961693	59
2	0877353	9961438	58
3	0880251	9961183	57
4	0883148	9960926	56
5	0886046	9960669	55
6	0888943	9960411	54
7	0891840	9960152	53
8	0894738	9959892	52
9	0897635	9959631	51
10	0900532	9959370	50
11	0903429	9959107	49
12	0906326	9958844	48
13	0909223	9958580	47
14	0912119	6958315	46
15	0915016	9958049	45
16	0917913	9957783	44
17	0920809	9957515	43
18	0923706	9957247	42
19	0926602	9956978	41
20	0929499	9956708	40
21	0932395	9956437	39
22	0935291	9956165	38
23	0938187	9955893	37
24	0941083	9855620	36
25	0943979	9955345	35
26	0946875	9955070	34
27	0949771	9954795	33
28	0952666	9954518	32
29	0955562	9954240	31
30	0958458	9953962	30
31	0961353	9953683	29
32	0964248	9953403	28
33	0967144	9953122	27
34	0970039	9952840	26
35	0972934	9952557	25
36	0975829	9952274	24
37	0978724	9951990	23
38	0981619	9951705	22
39	0984514	9951419	21
40	0987408	9951132	20
41	0990303	9950844	19
42	0993197	9950556	18
43	0996092	9950266	17
44	0998986	9949976	16
45	1001881	9949685	15
46	1004775	9949393	14
47	1007669	9949101	13
48	1010563	9948807	12
49	1013457	9948513	11
50	1016351	9948217	10
51	1019245	9947921	9
52	1022138	9917625	8
53	1025032	9947327	7
54	1027925	9947028	6
55	1030819	9946729	5
56	1033712	9946428	4
57	1036605	9946127	3
58	1039499	9945825	2
59	1042392	9945523	1
60	1045285	9945219	0
	Cosine	Sine	

Deg. 84.

6 Deg.			
	Sine	Cosine	
0	1045285	9945219	60
1	1048178	9944914	59
2	1051070	9944609	58
3	1053963	9944303	57
4	1056856	9943996	56
5	1059748	9943688	55
6	1062641	9943379	54
7	1065533	9943070	53
8	1068425	9942760	52
9	1071318	9942448	51
10	1074210	9942136	50
11	1077102	9941823	49
12	1079994	9941510	48
13	1082885	9941195	47
14	1085777	9940880	46
15	1088669	9940563	45
16	1091560	9940246	44
17	1094452	9939929	43
18	1097343	9939610	42
19	1100234	9939290	41
20	1103126	9938969	40
21	1106017	9938648	39
22	1108908	9938326	38
23	1111799	9938003	37
24	1114689	9937679	36
25	1117580	9937355	35
26	1120471	9937029	34
27	1123361	9936703	33
28	1126252	9936375	32
29	1129142	9936047	31
30	1132032	9935719	30
31	1134922	9935389	29
32	1137812	9935058	28
33	1140702	9934727	27
34	1143592	9934395	26
35	1146482	9934062	25
36	1149372	9933728	24
37	1152261	9933393	23
38	1155151	9933057	22
39	1158040	9932721	21
40	1160929	9932384	20
41	1163818	9932045	19
42	1166707	9931706	18
43	1169596	9931367	17
44	1172485	9931026	16
45	1175374	9930685	15
46	1178263	9930342	14
47	1181151	9929999	13
48	1184040	9929655	12
49	1186928	9929310	11
50	1189816	9928965	10
51	1192704	9928618	9
52	1195593	9928271	8
53	1198481	9927922	7
54	1201368	9927573	6
55	1204256	9927224	5
56	1207144	9926873	4
57	1210031	9926521	3
58	1212919	9926169	2
59	1215806	9925816	1
60	1218693	9925462	0
	Cosine	Sine	
	Deg. 83.		

7 Deg.			
	Sine	Cosine	
0	1218693	9925462	60
1	1221581	9925107	59
2	1224468	9924751	58
3	1227355	9924394	57
4	1230241	9924037	56
5	1233128	9923679	55
6	1236015	9923319	54
7	1238901	9922959	53
8	1241788	9922599	52
9	1244674	9922237	51
10	1247560	9921874	50
11	1250446	9921511	49
12	1253332	9921147	48
13	1256218	9920782	47
14	1259104	9920416	46
15	1261990	9920049	45
16	1264875	9919682	44
17	1267761	9919314	43
18	1270646	9918944	42
19	1273531	9918574	41
20	1276416	9918204	40
21	1279302	9917832	39
22	1282186	9917459	38
23	1285071	9917086	37
24	1287956	9916712	36
25	1290841	9916337	35
26	1293725	9915961	34
27	1296609	9915584	33
28	1299494	9915206	32
29	1302378	9914828	31
30	1305262	9914449	30
31	1308146	9914069	29
32	1311030	9913688	28
33	1313913	9913306	27
34	1316797	9912923	26
35	1319681	9912540	25
36	1322564	9912155	24
37	1325447	9911770	23
38	1328330	9911384	22
39	1331213	9910997	21
40	1334096	9910610	20
41	1336979	9910221	19
42	1339862	9909832	18
43	1342744	9909442	17
44	1345627	9909051	16
45	1348509	9908659	15
46	1351392	9908266	14
47	1354274	9907873	13
48	1357156	9907478	12
49	1360038	9907083	11
50	1362919	9906687	10
51	1365801	9906290	9
52	1368683	9905893	8
53	1371564	9905494	7
54	1374445	9905095	6
55	1377327	9904694	5
56	1380208	9904293	4
57	1383089	9903891	3
58	1385970	9903489	2
59	1388850	9903085	1
60	1391731	9902681	0
	Cosine	Sine	
	Deg. 82.		

8 Deg			
	Sine	Cosine	
0	[illegible]	[illegible]	60
1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58
3	[illegible]	[illegible]	57
4	[illegible]	[illegible]	56
5	[illegible]	[illegible]	55
6	[illegible]	[illegible]	54
7	[illegible]	[illegible]	53
8	[illegible]	[illegible]	52
9	[illegible]	[illegible]	51
10	[illegible]	[illegible]	50
11	[illegible]	[illegible]	49
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13	[illegible]	[illegible]	47
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16	[illegible]	[illegible]	44
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21	[illegible]	[illegible]	39
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39	[illegible]	[illegible]	21
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44	[illegible]	[illegible]	16
45	[illegible]	[illegible]	15
46	1524100	[illegible]	14
47	[illegible]	[illegible]	13
48	[illegible]	[illegible]	12
49	[illegible]	[illegible]	11
50	[illegible]	9881392	10
51	1538482	9880945	9
52	1541356	9880497	8
53	1544230	9880048	7
54	1547104	9879599	6
55	1549978	9879148	5
56	1552851	9878697	4
57	1555725	9878245	3
58	1558598	9877792	2
59	1561472	9877338	1
60	1564345	9876883	0
	Cosine	Sine	
	Deg. 81.		

	9 Deg.				10 Deg.				11 Deg.		
	Sine	Cosine			Sine	Cosine			Sine	Cosine	
0	1564345	9876883	60	0	1736482	9848078	60	0	1908090	9816272	60
1	1567218	9876428	59	1	1739346	9847572	59	1	1910945	9815716	59
2	1570091	9875972	58	2	1742211	9847066	58	2	1913801	9815160	58
3	1572963	9875514	57	3	1745075	9846558	57	3	1916656	9814603	57
4	1575836	9875057	56	4	1747939	9846050	56	4	1919510	9814045	56
5	1578708	9874598	55	5	1750803	9845542	55	5	1922365	9813486	55
6	1581581	9874138	54	6	1753667	9845032	54	6	1925220	9812927	54
7	1584453	9873678	53	7	1756531	9844521	53	7	1928074	9812366	53
8	1587325	9873216	52	8	1759395	9844010	52	8	1930928	9811805	52
9	1590197	9872754	51	9	1762258	9843498	51	9	1933782	9811243	51
10	1593069	9872291	50	10	1765121	9842985	50	10	1936636	9810680	50
11	1595940	9871827	49	11	1767984	9842471	49	11	1939490	9810116	49
12	1598812	9871363	48	12	1770847	9841956	48	12	1942344	9809552	48
13	1601683	9870897	47	13	1773710	9841441	47	13	1945197	9808986	47
14	1604555	9870431	46	14	1776573	9840924	46	14	1948050	9808420	46
15	1607426	9869964	45	15	1779435	9840407	45	15	1950903	9807853	45
16	1610297	9869496	44	16	1782298	9839889	44	16	1953756	9807285	44
17	1613167	9869027	43	17	1785160	9839370	43	17	1956609	9806716	43
18	1616038	9868557	42	18	1788022	9838850	42	18	1959461	9806147	42
19	1618909	9868087	41	19	1790884	9838330	41	19	1962314	9805576	41
20	1621779	9867615	40	20	1793746	9837808	40	20	1965166	9805005	40
21	1624650	9867143	39	21	1796607	9837286	39	21	1968018	9804433	39
22	1627520	9866670	38	22	1799469	9836763	38	22	1970870	9803860	38
23	1630390	9866196	37	23	1802330	9836239	37	23	1973722	9803286	37
24	1633260	9865722	36	24	1805191	9835715	36	24	1976573	9802712	36
25	1636129	9865246	35	25	1808052	9835189	35	25	1979425	9802136	35
26	1638999	9864770	34	26	1810913	9834663	34	26	1982276	9801560	34
27	1641868	9864293	33	27	1813774	9834136	33	27	1985127	9800983	33
28	1644738	9863815	32	28	1816635	9833608	32	28	1987978	9800405	32
29	1647607	9863336	31	29	1819495	9833079	31	29	1990829	9799827	31
30	1650476	9862856	30	30	1822355	9832549	30	30	1993679	9799247	30
31	1653345	9862375	29	31	1825215	9832019	29	31	1996530	9798667	29
32	1656214	9861894	28	32	1828075	9831487	28	32	1999380	9798086	28
33	1659082	9861412	27	33	1830935	9830955	27	33	2002230	9797504	27
34	1661951	9860929	26	34	1833795	9830422	26	34	2005080	9796921	26
35	1664819	9860445	25	35	1836654	9829888	25	35	2007930	9796337	25
36	1667687	9859960	24	36	1839514	9829353	24	36	2010779	9795752	24
37	1670556	9859475	23	37	1842373	9828818	23	37	2013629	9795167	23
38	1673423	9858988	22	38	1845232	9828282	22	38	2016478	9794581	22
39	1676291	9858501	21	39	1848091	9827744	21	39	2019327	9793994	21
40	1679159	9858013	20	40	1850949	9827206	20	40	2022176	9793406	20
41	1682026	9857524	19	41	1853808	9826668	19	41	2025024	9792818	19
42	1684894	9857035	18	42	1856666	9826128	18	42	2027873	9792228	18
43	1687761	9856544	17	43	1859524	9825587	17	43	2030721	9791638	17
44	1690628	9856053	16	44	1862382	9825046	16	44	2033569	9791047	16
45	1693495	9855561	15	45	1865240	9824504	15	45	2036418	9790455	15
46	1696362	9855068	14	46	1868098	9823961	14	46	2039265	9789862	14
47	1699228	9854574	13	47	1870956	9823417	13	47	2042113	9789268	13
48	1702095	9854079	12	48	1873813	9822873	12	48	2044961	9788674	12
49	1704961	9853583	11	49	1876670	9822327	11	49	2047808	9788079	11
50	1707828	9853087	10	50	1879528	9821781	10	50	2050655	9787483	10
51	1710694	9852590	9	51	1882385	9821234	9	51	2053502	9786886	9
52	1713560	9852092	8	52	1885241	9820686	8	52	2056349	9786288	8
53	1716425	9851593	7	53	1888098	9820137	7	53	2059195	9785689	7
54	1719291	9851093	6	54	1890954	9819587	6	54	2062042	9785090	6
55	1722156	9850593	5	55	1893811	9819037	5	55	2064888	9784490	5
56	1725022	9850091	4	56	1896667	9818485	4	56	2067734	9783889	4
57	1727887	9849589	3	57	1899523	9817933	3	57	2070580	9783287	3
58	1730752	9849086	2	58	1902379	9817380	2	58	2073426	9782684	2
59	1733617	9848582	1	59	1905234	9816826	1	59	2076272	9782080	1
60	1736482	9848078	0	60	1908090	9816272	0	60	2079117	9781476	0
	Cosine	Sine			Cosine	Sine			Cosine	Sine	
	Deg. 80.				Deg. 79.				Deg. 78.		

	12 Deg.				13 Deg.				14 Deg.		
	Sine	Cosine			Sine	Cosine			Sine	Cosine	
0	2079117	9781476	60	0	2249511	9743701	60	0	2419219	9702957	60
1	2081962	9780871	59	1	2252345	9743046	59	1	2422041	9702253	59
2	2084807	9780265	58	2	2255179	9742390	58	2	2424863	9701548	58
3	2087652	9779658	57	3	2258013	9741734	57	3	2427685	9700842	57
4	2090497	9779050	56	4	2260846	9741077	56	4	2430507	9700136	56
5	2093341	9778442	55	5	2263680	9740419	55	5	2433329	9699428	55
6	2096186	9777832	54	6	2266513	9739760	54	6	2436150	9698720	54
7	2099030	9777222	53	7	2269346	9739100	53	7	2438971	9698011	53
8	2101874	9776611	52	8	2272179	9738439	52	8	2441792	9697301	52
9	2104718	9775999	51	9	2275012	9737778	51	9	2444613	9696591	51
10	2107561	9775387	50	10	2277844	9737116	50	10	2447433	9695879	50
11	2110405	9774773	49	11	2280677	9736453	49	11	2450254	9695167	49
12	2113248	9774159	48	12	2283509	9735789	48	12	2453074	9694453	48
13	2116091	9773544	47	13	2286341	9735124	47	13	2455894	9693740	47
14	2118934	9772928	46	14	2289172	9734459	46	14	2458713	9693025	46
15	2121777	9772311	45	15	2292004	9733793	45	15	2461533	9692309	45
16	2124619	9771693	44	16	[illegible]	[illegible]	44	16	[illegible]	[illegible]	44
17	2127462	9771075	43	17	2297666	9732458	43	17	2467171	9690875	43
18	2130304	9770456	42	18	[illegible]	[illegible]	42	18	[illegible]	[illegible]	42
19	2133146	9769836	41	19	2303328	9731119	41	19	2472809	9689438	41
20	2135988	9769215	40	20	2306159	9730449	40	20	2475627	9688719	40
21	2138829	9768593	39	21	2308989	9729777	39	21	2478445	9687998	39
22	2141671	9767970	38	22	2311819	9729105	38	22	2481263	9687277	38
23	2144512	9767347	37	23	2314649	9728432	37	23	2484081	9686555	37
24	2147353	9766723	36	24	[illegible]	[illegible]	36	24	[illegible]	[illegible]	36
25	2150194	9766098	35	25	2320309	9727084	35	25	2489716	9685108	35
26	2153035	9765472	34	26	2323138	[illegible]	34	26	[illegible]	[illegible]	34
27	2155876	9764845	33	27	[illegible]	[illegible]	33	27	[illegible]	[illegible]	33
28	2158716	9764218	32	28	2328796	9725050	32	28	2498167	9682931	32
29	2161556	9763589	31	29	2331625	9724378	31	29	2500984	9682204	31
30	2164396	9762960	30	30	2334454	9723699	30	30	2503800	9681476	30
31	2167236	9762330	29	31	2337282	9723020	29	31	2506616	9680748	29
32	2170076	9761699	28	32	2340110	9722339	28	32	2509432	9680018	28
33	2172915	9761068	27	33	[illegible]	[illegible]	27	33	[illegible]	[illegible]	27
34	2175754	9760435	26	34	[illegible]	[illegible]	26	34	[illegible]	[illegible]	26
35	2178593	9759802	25	35	2348594	9720294	25	35	2517879	9677825	25
36	2181432	9759168	24	36	2351421	9719610	24	36	2520694	9677092	24
37	2184271	9758533	23	37	2354248	9718926	23	37	2523508	9676358	23
38	2187110	9757897	22	38	2357075	9718240	22	38	2526323	9675624	22
39	2189948	9757260	21	39	2359902	9717554	21	39	2529137	9674888	21
40	2192786	9756623	20	40	2362729	9716867	20	40	2531952	9674152	20
41	2195624	9755985	19	41	[illegible]	[illegible]	19	41	[illegible]	[illegible]	19
42	2198462	9755345	18	42	2368381	9715491	18	42	2537579	9672678	18
43	2201300	9754706	17	43	2371207	9714802	17	43	2540393	9671939	17
44	2204137	9754065	16	44	2374033	9714112	16	44	2543206	9671200	16
45	2206974	9753423	15	45	2376859	9713421	15	45	2546019	9670459	15
46	2209811	9752781	14	46	2379684	9712729	14	46	2548832	9669718	14
47	2212648	9752138	13	47	2382510	9712036	13	47	2551645	9668977	13
48	2215485	9751494	12	48	2385335	9711343	12	48	2554458	9668234	12
49	2218321	9750849	11	49	2388159	9710649	11	49	2557270	9667490	11
50	2221158	9750203	10	50	2390984	9709953	10	50	2560082	9666746	10
51	2223994	9749556	9	51	2393808	9709258	9	51	2562894	9666001	9
52	2226830	9748909	8	52	2396633	9708561	8	52	2565705	9665255	8
53	2229666	9748261	7	53	[illegible]	[illegible]	7	53	[illegible]	[illegible]	7
54	2232501	9747612	6	54	2402280	9707165	6	54	2571328	9663761	6
55	2235337	9746962	5	55	2405104	9706466	5	55	2574139	9663012	5
56	2238172	9746311	4	56	2407927	9705766	4	56	2576950	9662263	4
57	2241007	9745660	3	57	2410751	9705065	3	57	2579760	9661513	3
58	2243842	9745008	2	58	2413574	9704363	2	58	2582570	9660762	2
59	2246676	9744355	1	59	[illegible]	[illegible]	1	59	[illegible]	[illegible]	1
60	2249511	9743701	0	60	2419219	9702957	0	60	2588190	9659258	0
	Cosine	Sine			Cosine	Sine			Cosine	Sine	
	Deg. 77.				Deg. 76.				Deg. 75.		

15 Deg.				16 Deg.				17 Deg.			
	Sine	Cosine			Sine	Cosine			Sine	Cosine	
0	2588190	9659258	60	0	2756374	9612617	60	0	2923717	9563048	60
1	[illegible]	[illegible]	59	1	[illegible]	9611815	59	1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58	2	[illegible]	9611012	58	2	[illegible]	9561345	58
3	[illegible]	[illegible]	57	3	[illegible]	[illegible]	57	3	[illegible]	[illegible]	57
4	[illegible]	[illegible]	56	4	[illegible]	[illegible]	56	4	2934842	[illegible]	56
5	[illegible]	[illegible]	55	5	[illegible]	9608568	55	5	[illegible]	[illegible]	55
6	2605045	9654726	54	6	2773147	9607792	54	6	2940403	9557930	54
7	[illegible]	[illegible]	53	7	[illegible]	[illegible]	53	7	2943183	[illegible]	53
8	[illegible]	[illegible]	52	8	[illegible]	[illegible]	52	8	2945963	9556218	52
9	2613469	9652449	51	9	2781530	9605368	51	9	2948743	9555361	51
10	2616277	9651689	50	10	2784324	9604558	50	10	2951522	9554502	50
11	2619085	9650927	49	11	2787118	9603748	49	11	2954302	9553643	49
12	2621892	9650165	48	12	2789911	9602937	48	12	2957081	9552784	48
13	2624699	9640402	47	13	2792704	9602125	47	13	2959859	9551923	47
14	2627506	9648638	46	14	2795497	9601312	46	14	2962638	9551062	46
15	2630312	9647873	45	15	2798290	9600499	45	15	2965416	9550199	45
16	[illegible]	[illegible]	44	16	2801083	[illegible]	44	16	[illegible]	[illegible]	44
17	2635925	9646341	43	17	2803875	9598869	43	17	2970971	9548473	43
18	2638730	9645574	42	18	2806667	9598053	42	18	2973749	9547608	42
19	[illegible]	[illegible]	41	19	[illegible]	[illegible]	41	19	[illegible]	[illegible]	41
20	2644342	9644037	40	20	2812251	9596418	40	20	2979303	9545876	40
21	2647147	9643268	39	21	2815042	9595600	39	21	2982079	9545009	39
22	2649952	9642497	38	22	2817833	9594781	38	22	2084856	9544141	38
23	2652757	9641726	37	23	2820624	9593961	37	23	2987632	9543273	37
24	2655561	9640954	36	24	2823415	9593140	36	24	2950408	9542403	36
25	2658366	9640181	35	25	2826205	9592318	35	25	2993184	9541533	35
26	2661170	9639407	34	26	2828995	9591496	34	26	2995959	9540662	34
27	[illegible]	[illegible]	33	27	[illegible]	[illegible]	33	27	[illegible]	[illegible]	33
28	2666777	9637858	32	28	2834575	9589848	32	28	3001509	9538917	32
29	[illegible]	[illegible]	31	29	[illegible]	[illegible]	31	29	[illegible]	[illegible]	31
30	2672384	9636305	30	30	2840153	9588197	30	30	3007058	9537170	30
31	[illegible]	[illegible]	29	31	[illegible]	[illegible]	29	31	[illegible]	[illegible]	29
32	2677989	9634748	28	32	2845731	9586543	28	32	3012606	9535418	28
33	2680792	9633969	27	33	2848520	9585715	27	33	3015380	9534542	27
34	2683594	9633189	26	34	2851308	9584886	26	34	3018153	9533664	26
35	2686396	9632408	25	35	2854096	9584056	25	35	3020926	9532786	25
36	[illegible]	[illegible]	24	36	[illegible]	[illegible]	24	36	[illegible]	[illegible]	24
37	2692000	9630843	23	37	2859671	9582394	23	37	3026471	9531027	23
38	2694801	9630060	22	38	2862458	9581562	22	38	3029244	9530146	22
39	2697602	9629275	21	39	2865246	9580729	21	39	3032016	9529264	21
40	2700403	9628190	20	40	2868032	9579895	20	40	3034788	9528382	20
41	2703204	9627074	19	41	2870819	9579060	19	41	3037559	9527499	19
42	2706004	9626917	18	42	2873605	9578225	18	42	3040331	9526615	18
43	2708805	9626130	17	43	2876391	9577389	17	43	3043102	9525730	17
44	2711605	9625342	16	44	2879177	9576552	16	44	3045872	9524844	16
45	2714404	9624552	15	45	2881963	9575714	15	45	3048643	9523958	15
46	2717204	9623762	14	46	2884748	9574875	14	46	3051413	9523071	14
47	2720003	9622972	13	47	2887533	9574035	13	47	3054183	9522183	13
48	2722802	9622180	12	48	2890318	9573195	12	48	3056953	9521294	12
49	2725601	9621387	11	49	2893103	9572354	11	49	3059723	9520404	11
50	2728400	9620594	10	50	2895887	9571512	10	50	3062492	9519514	10
51	2731198	9619800	9	51	2898671	9570669	9	51	3065261	9518623	9
52	2733997	9619005	8	52	2901455	9569825	8	52	3068030	9517731	8
53	2736794	9618210	7	53	2904239	9568981	7	53	3070798	9516838	7
54	2739592	9617413	6	54	2907022	9568136	6	54	3073566	9515944	6
55	2742390	9616616	5	55	2909805	9567290	5	55	3076334	9515050	5
56	2745187	9615818	4	56	2912588	9566443	4	56	3079102	9514151	4
57	2747984	9615010	3	57	2915371	9565595	3	57	[illegible]	[illegible]	3
58	2750781	9614219	2	58	2918153	9564747	2	58	3084636	9512361	2
59	2753577	9613418	1	59	2920935	9563898	1	59	3087403	9511464	1
60	2756374	9612617	0	60	2923717	9563048	0	60	3090170	9510565	0
	Cosine	Sine			Cosine	Sine			Cosine	Sine	
Deg. 74.				Deg. 73				Deg. 72.			

18 Deg.			
	Sine	Cosine	
0	3090170	9510565	60
1	3092936	9509666	59
2	3095702	9508766	58
3	3098468	9507865	57
4	3101234	9506963	56
5	3103999	9506061	55
6	3106764	9505157	54
7	3109529	9504253	53
8	3112294	9503348	52
9	3115058	9502443	51
10	3117822	9501536	50
11	3120586	9500629	49
12	3123349	9499721	48
13	3126112	9498812	47
14	3128875	9497902	46
15	3131638	9496991	45
16	3134400	9496080	44
17	3137163	9495168	43
18	3139925	9494255	42
19	3142686	9493341	41
20	3145448	9492426	40
21	3148209	9491511	39
22	3150969	9490595	38
23	3153730	9489678	37
24	3156490	9488760	36
25	3159250	9487842	35
26	3162010	9486922	34
27	3164770	9486002	33
28	3167529	9485081	32
29	3170288	9484159	31
30	3173047	9483237	30
31	3175805	9482313	29
32	3178563	9481389	28
33	3181321	9480464	27
34	3184079	9479538	26
35	3186836	9478612	25
36	3189593	9477684	24
37	3192350	9476756	23
38	3195106	9475827	22
39	3197863	9474897	21
40	3200619	9473966	20
41	3203374	9473035	19
42	3206130	9472103	18
43	3208885	9471170	17
44	3211640	9470236	16
45	3214395	9469301	15
46	3217149	9468366	14
47	3219903	9467430	13
48	3222657	9466493	12
49	3225411	9465555	11
50	3228164	9464616	10
51	3230917	9463677	9
52	3233670	9462736	8
53	3236422	9461795	7
54	3239174	9460854	6
55	3241926	9459911	5
56	3244678	9458968	4
57	3247429	9458023	3
58	3250180	9457078	2
59	3252931	9456132	1
60	3255682	9455186	0
	Cosine	Sine	
		Deg. 71.	

19 Deg.			
	Sine	Cosine	
0	3255682	9455186	60
1	3258432	9454238	59
2	3261182	9453290	58
3	3263932	9452341	57
4	3266681	9451391	56
5	3269430	9450441	55
6	3272179	9449489	54
7	3274928	9448537	53
8	327,676	9447584	52
9	3280424	9446630	51
10	3283172	9445675	50
11	3285919	9444720	49
12	3288666	9443764	48
13	3291413	9442807	47
14	3294160	9441849	46
15	3296906	9440890	45
16	3299653	9439931	44
17	3302398	9438971	43
18	3305144	9438010	42
19	3307889	9437048	41
20	3310634	9436085	40
21	3313379	9435122	39
22	3316123	9434157	38
23	3318867	9433192	37
24	3321611	9432227	36
25	3324355	9431260	35
26	3327098	9430293	34
27	3329841	9429324	33
28	3332584	9428355	32
29	3335326	9427386	31
30	[illegible]	9426415	30
31	3340810	9425444	29
32	3343552	[illegible]	28
33	3346293	9423498	27
34	3349034	9422525	26
35	3351775	9421550	25
36	3354516	9420575	24
37	3357256	9419598	23
38	3359996	[illegible]	22
39	3362735	[illegible]	21
40	3365475	9416665	20
41	3368214	9415686	19
42	3370953	9414705	18
43	3373691	[illegible]	17
44	3376429	9412743	16
45	3379167	9411760	15
46	3381905	9410777	14
47	3384642	[illegible]	13
48	3387379	[illegible]	12
49	3390116	[illegible]	11
50	3392852	[illegible]	10
51	3395589	9405848	9
52	3398325	9404860	8
53	3401060	9403871	7
54	3403796	9402881	6
55	3406531	9401891	5
56	3409265	9400899	4
57	3412000	9399907	3
58	3414734	[illegible]	2
59	3417468	9397921	1
60	3420201	9396926	0
	Cosine	Sine	
		Deg. 70.	

20 Deg.			
	Sine	Cosine	
0	3420201	9396926	60
1	3422935	9395931	59
2	[illegible]	9394935	58
3	3428400	9393938	57
4	3431133	9392940	56
5	3433865	9391942	55
6	3436597	9390943	54
7	3439329	9389942	53
8	3442060	9388942	52
9	3444791	9387940	51
10	3447521	9386938	50
11	3450252	9385934	49
12	3452982	[illegible]	48
13	3455712	[illegible]	47
14	3458441	[illegible]	46
15	3461171	[illegible]	45
16	3463900	[illegible]	44
17	3466628	[illegible]	43
18	3469357	[illegible]	42
19	3472085	[illegible]	41
20	3474812	[illegible]	40
21	3477540	[illegible]	39
22	3480267	[illegible]	38
23	3482994	[illegible]	37
24	3485720	[illegible]	36
25	3488447	9371800	35
26	3491173	9370790	34
27	3493898	9369774	33
28	3496624	9368758	32
29	3499349	9367740	31
30	3502074	9366722	30
31	3504798	9365703	29
32	3507523	9364683	28
33	3510247	9363662	27
34	[illegible]	[illegible]	26
35	3515693	9361618	25
36	3518416	9360595	24
37	3521139	9359571	23
38	3523862	9358547	22
39	3526584	9357521	21
40	[illegible]	9356495	20
41	[illegible]	9355468	19
42	3534748	9354440	18
43	3537469	9353412	17
44	3540190	9352382	16
45	3542910	9351352	15
46	3545630	9350321	14
47	3548350	[illegible]	13
48	3551070	[illegible]	12
49	3553789	[illegible]	11
50	3556508	[illegible]	10
51	3559226	9345154	9
52	3561944	9344119	8
53	3564662	9343082	7
54	3567380	9342045	6
55	3570097	9341007	5
56	3572814	9339968	4
57	[illegible]	9338928	3
58	3578248	9337888	2
59	[illegible]	9336846	1
60	3583679	9335804	0
	Cosine	Sine	
		Deg. 69.	

21 Deg.	Sine	Cosine	
0	3583679	9335804	60
1	3586395	9334761	59
2	3589110	9333718	58
3	3591825	9332673	57
4	3594540	9331628	56
5	3597254	9330582	55
6	3599968	9329535	54
7	3602682	9328488	53
8	3605395	9327439	52
9	3608108	9326390	51
10	3610821	9325340	50
11	3613534	9324200	49
12	3616246	9323238	48
13	3618958	9322186	47
14	3621669	9321133	46
15	3624380	9320079	45
16	3627091	9319024	44
17	3629802	9317969	43
18	3632512	9316912	42
19	3635222	9315855	41
20	3637932	9314797	40
21	3640641	9313739	39
22	3643351	9312679	38
23	3646059	9311616	37
24	3648768	9310555	36
25	3651476	9309496	35
26	3654184	9308434	34
27	3656891	9307370	33
28	3659599	9306306	32
29	3662306	9305241	31
30	3665012	9304176	30
31	3667719	9303109	29
32	3670425	9302042	28
33	3673130	9300974	27
34	3675836	9299905	26
35	3678541	9298835	25
36	[illegible]	9297765	24
37	[illegible]	9296694	23
38	[illegible]	9295622	22
39	[illegible]	9294549	21
40	[illegible]	9293475	20
41	3694765	9292401	19
42	3697468	9291326	18
43	3700170	9290250	17
44	3702872	9289173	16
45	3705574	9288096	15
46	3708276	9287017	14
47	3710977	9285938	13
48	3713678	9284858	12
49	3716379	9283778	11
50	3719079	9282696	10
51	3721780	9281614	9
52	3724479	9280531	8
53	3727179	9279447	7
54	3729878	9278363	6
55	3732577	9277277	5
56	3735275	9276191	4
57	3737973	9275104	3
58	3740671	9274016	2
59	3743369	9272928	1
60	3746066	9271839	0
	Cosine	Sine	
	Deg. 68.		

22 Deg.	Sine	Cosine	
0	3746066	9271839	60
1	3748763	[illegible]	59
2	3751459	[illegible]	58
3	3754156	[illegible]	57
4	3756852	[illegible]	56
5	3759547	[illegible]	55
6	3762243	[illegible]	54
7	3764938	[illegible]	53
8	3767632	[illegible]	52
9	3770327	[illegible]	51
10	3773021	[illegible]	50
11	3775714	9259805	49
12	3778408	9258706	48
13	3781101	9257606	47
14	3783794	9256506	46
15	3786486	9255405	45
16	3789178	9254303	44
17	3791870	9253201	43
18	3794562	9252097	42
19	3797253	9250993	41
20	3799944	9249888	40
21	3802634	9248782	39
22	3805324	9247676	38
23	3808014	9246568	37
24	3810704	9245460	36
25	3813393	9244351	35
26	3816082	9243242	34
27	3818770	9242131	33
28	3821459	9241020	32
29	3824147	9239908	31
30	3826834	9238795	30
31	3829522	9237682	29
32	3832209	9236567	28
33	3834895	9235452	27
34	3837582	9234336	26
35	3840268	9233220	25
36	3842953	9232102	24
37	3845639	9230984	23
38	3848324	9229865	22
39	3851008	9228745	21
40	3853693	9227624	20
41	3856377	9226503	19
42	3859060	9225381	18
43	3861744	9224258	17
44	3864427	9223134	16
45	3867110	9222010	15
46	3869792	9220884	14
47	3872474	9219758	13
48	3875156	9218632	12
49	3877837	9217504	11
50	3880518	9216375	10
51	3883199	9215246	9
52	3885880	9214116	8
53	3888560	9212986	7
54	3891240	9211854	6
55	3893919	9210722	5
56	3896598	9209589	4
57	3899277	9208455	3
58	3901955	9207320	2
59	3904633	9206185	1
60	3907311	9205049	0
	Cosine	Sine	
	Deg. 67.		

23 Deg.	Sine	Cosine	
0	3907311	9205049	60
1	3909989	9203912	59
2	3912666	9202774	58
3	3915343	9201635	57
4	3918019	9200496	56
5	3920695	9199356	55
6	3923371	9198215	54
7	3926047	9197073	53
8	3928722	9195931	52
9	3931397	9194788	51
10	3934071	9193644	50
11	3936745	9192499	49
12	3939419	9191353	48
13	3942093	9190207	47
14	3944766	9189060	46
15	3947439	9187912	45
16	3950111	9186763	44
17	3952783	9185614	43
18	3955455	9184464	42
19	3958127	9183313	41
20	3960798	9182161	40
21	3963468	9181009	39
22	3966139	9179855	38
23	3968809	9178701	37
24	3971479	9177546	36
25	3974148	9176391	35
26	3976818	9175234	34
27	3979486	9174077	33
28	3982155	9172919	32
29	3984823	9171760	31
30	3987491	9170601	30
31	3990158	9169440	29
32	3992825	9168279	28
33	3995492	9167118	27
34	3998158	9165955	26
35	4000825	9164791	25
36	4003490	9163627	24
37	4006156	9162462	23
38	4008821	9161297	22
39	4011486	9160130	21
40	4014150	9158963	20
41	4016814	9157795	19
42	4019478	9156626	18
43	4022141	9155456	17
44	4024804	9154286	16
45	4027467	9153115	15
46	4030129	9151943	14
47	4032791	9150770	13
48	4035453	9149597	12
49	4038114	9148422	11
50	4040775	9147247	10
51	4043436	9146072	9
52	4046096	9144895	8
53	4048756	9143718	7
54	4051416	9142540	6
55	4054075	9141361	5
56	4056734	9140181	4
57	4059393	9139001	3
58	4062051	9137819	2
59	4064709	9136637	1
60	4067366	9135455	0
	Cosine	Sine	
	Deg. 66.		

24 Deg.				25 Deg.				26 Deg.			
′	Sine	Cosine	′	′	Sine	Cosine	′	′	Sine	Cosine	′
0	4067366	9135455	60	0	4226183	9063078	60	0	4383711	[illegible]	60
1	4070024	9134271	59	1	4228819	9061848	59	1	4386326	[illegible]	59
2	4072681	9133087	58	2	4231455	9060618	58	2	4388940	[illegible]	58
3	4075337	9131902	57	3	4234090	9059386	57	3	4391553	[illegible]	57
4	4077993	9130716	56	4	4236725	9058154	56	4	4394166	[illegible]	56
5	4080649	9129529	55	5	4239360	9056922	55	5	4396779	[illegible]	55
6	4083305	9128342	54	6	4241994	9055688	54	6	[illegible]	[illegible]	54
7	4085960	9127154	53	7	4244628	9054454	53	7	[illegible]	[illegible]	53
8	4088615	9125965	52	8	4247262	9053219	52	8	[illegible]	[illegible]	52
9	4091269	9124775	51	9	4249895	9051983	51	9	[illegible]	[illegible]	51
10	4093923	9123584	50	10	4252528	9050746	50	10	[illegible]	[illegible]	50
11	4096577	9122393	49	11	4255161	9049509	49	11	[illegible]	[illegible]	49
12	4099230	9121201	48	12	4257793	9048271	48	12	[illegible]	[illegible]	48
13	4101883	9120008	47	13	4260425	9047032	47	13	[illegible]	[illegible]	47
14	4104536	9118815	46	14	4263056	9045792	46	14	[illegible]	[illegible]	46
15	4107189	9117620	45	15	4265687	9044551	45	15	[illegible]	[illegible]	45
16	4109841	9116425	44	16	4268318	9043310	44	16	[illegible]	[illegible]	44
17	4112492	9115229	43	17	4270949	9042068	43	17	[illegible]	[illegible]	43
18	4115144	9114033	42	18	4273579	9040825	42	18	[illegible]	[illegible]	42
19	4117795	9112835	41	19	4276208	9039582	41	19	[illegible]	[illegible]	41
20	4120445	9111637	40	20	4278838	9038338	40	20	[illegible]	[illegible]	40
21	4123096	9110438	39	21	4281467	[illegible]	39	21	[illegible]	[illegible]	39
22	4125745	9109238	38	22	4284095	[illegible]	38	22	[illegible]	[illegible]	38
23	4128395	9108038	37	23	4286723	[illegible]	37	23	[illegible]	[illegible]	37
24	4131044	9106837	36	24	4289351	[illegible]	36	24	[illegible]	[illegible]	36
25	4133693	9105635	35	25	4291979	[illegible]	35	25	4448957	[illegible]	35
26	4136342	9104432	34	26	4294606	[illegible]	34	26	4451562	[illegible]	34
27	4138990	9103228	33	27	4297233	[illegible]	33	27	4454167	[illegible]	33
28	4141638	9102024	32	28	4299859	[illegible]	32	28	4456771	[illegible]	32
29	[illegible]	[illegible]	31	29	[illegible]	[illegible]	31	29	4459375	[illegible]	31
30	4146932	9099613	30	30	4305111	[illegible]	30	30	4461978	[illegible]	30
31	4149579	9098406	29	31	4307736	[illegible]	29	31	4464581	[illegible]	29
32	4152226	9097199	28	32	4310361	[illegible]	28	32	4467184	[illegible]	28
33	4154872	9095990	27	33	4312986	[illegible]	27	33	4469786	[illegible]	27
34	4157517	9094781	26	34	4315610	[illegible]	26	34	4472388	[illegible]	26
35	4160163	9093572	25	35	4318234	[illegible]	25	35	4474990	[illegible]	25
36	4162808	9092361	24	36	4320857	[illegible]	24	36	[illegible]	[illegible]	24
37	4165453	9091150	23	37	4323481	[illegible]	23	37	4480192	[illegible]	23
38	4168097	9089938	22	38	4326103	[illegible]	22	38	4482792	[illegible]	22
39	4170741	9088725	21	39	4328726	9014551	21	39	4485392	[illegible]	21
40	4173385	9087511	20	40	4331348	9013 02	20	40	4487992	[illegible]	20
41	4176028	9086297	19	41	4333970	9012031	19	41	4490591	8935021	19
42	4178671	9085082	18	42	4336591	9010770	18	42	4493190	[illegible]	18
43	4181313	9083866	17	43	4339212	9009508	17	43	4495789	[illegible]	17
44	4183956	9082649	16	44	4341832	9008246	16	44	4498387	[illegible]	16
45	4186597	9081432	15	45	4344453	9006982	15	45	4500984	[illegible]	15
46	4189239	9080214	14	46	4347072	9005718	14	46	4503582	[illegible]	14
47	4191880	9078995	13	47	4349692	[illegible]	13	47	4506179	[illegible]	13
48	4194521	9077775	12	48	4352311	[illegible]	12	48	4508775	[illegible]	12
49	4197161	9076554	11	49	4354930	[illegible]	11	49	4511372	[illegible]	11
50	4199801	9075333	10	50	4357548	[illegible]	10	50	4513967	[illegible]	10
51	4202441	9074111	9	51	4360166	[illegible]	9	51	4516563	8921920	9
52	4205080	9072888	8	52	4362784	[illegible]	8	52	4519158	8920606	8
53	4207719	9071665	7	53	4365401	[illegible]	7	53	4521753	8919291	7
54	4210358	9070440	6	54	4368018	[illegible]	6	54	4524347	8917975	6
55	4212996	9069215	5	55	4370634	[illegible]	5	55	4526941	8916659	5
56	4215634	9067989	4	56	4373251	[illegible]	4	56	4529535	8915342	4
57	4218272	9066762	3	57	4375866	[illegible]	3	57	4532128	8914024	3
58	4220909	9065535	2	58	4378482	[illegible]	2	58	4534721	8912705	2
59	4223546	9064307	1	59	4381097	[illegible]	1	59	4537313	8911385	1
60	4226183	9063078	0	60	4383711	[illegible]	0	60	4539905	8910065	0
′	Cosine	Sine	′	′	Cosine	Sine	′	′	Cosine	Sine	′
Deg. 65.				Deg. 64.				Deg. 63.			

27 Deg.				28 Deg.				29 Deg.			
′	Sine	Cosine	′	′	Sine	Cosine	′	′	Sine	Cosine	′
0	4539905	8010065	60	0	4694716	8829476	60	0	4848096	8746197	60
1	4542497	8908744	59	1	4697284	8828110	59	1	4850640	8744786	59
2	4545088	8907423	58	2	4699852	8826743	58	2	4853184	8743375	58
3	4547679	8906100	57	3	4702419	8825376	57	3	4855727	8741963	57
4	[illegible]	8904777	56	4	4704986	8824007	56	4	4858270	8740550	56
5	4552859	8903453	55	5	4707553	8822638	55	5	4860812	8739137	55
6	4555449	[illegible]	54	6	4710119	8821260	54	6	4863354	8737722	54
7	4558038	[illegible]	53	7	4712685	8819898	53	7	4865895	8736307	53
8	4560627	[illegible]	52	8	4715250	8818527	52	8	4868436	8734891	52
9	4563216	[illegible]	51	9	4717815	8817155	51	9	4870977	8733475	51
10	4565804	[illegible]	50	10	4720380	8815782	50	10	4873517	8732058	50
11	4568392	[illegible]	49	11	4722944	8814409	49	11	4876057	8730640	49
12	4570979	[illegible]	48	12	4725508	8813035	48	12	4878597	8729221	48
13	4573566	[illegible]	47	13	4728071	8811660	47	13	4881136	8727801	47
14	4576153	[illegible]	46	14	4730634	8810284	46	14	4883674	8726381	46
15	4578739	[illegible]	45	15	4733197	8808907	45	15	4886212	8724960	45
16	4581325	[illegible]	44	16	4735759	8807530	44	16	4888750	8723538	44
17	[illegible]	[illegible]	43	17	4738321	8806152	43	17	4891288	8722116	43
18	[illegible]	[illegible]	42	18	4740882	8804774	42	18	4893825	8720693	42
19	[illegible]	[illegible]	41	19	4743443	8803394	41	19	4896361	8719269	41
20	[illegible]	[illegible]	40	20	4746004	8802014	40	20	4898897	8717844	40
21	4594248	[illegible]	39	21	4748564	8800633	39	21	4901433	8716419	39
22	4596832	[illegible]	38	22	4751124	8799251	38	22	4903968	8714993	38
23	4599415	[illegible]	37	23	4753683	8797869	37	23	4906503	8713566	37
24	[illegible]	[illegible]	36	24	4756242	8796486	36	24	4909038	8712138	36
25	4604580	[illegible]	35	25	4758801	8795102	35	25	4911572	8710710	35
26	4607162	[illegible]	34	26	4761359	8793717	34	26	4914105	8709281	34
27	4609744	[illegible]	33	27	4763917	8792332	33	27	4916638	8707851	33
28	4612325	[illegible]	32	28	4766474	8790946	32	28	4919171	8706420	32
29	4614906	[illegible]	31	29	4769031	8789559	31	29	4921704	8704989	31
30	4617486	[illegible]	30	30	4771588	8788171	30	30	4924236	8703557	30
31	4620066	[illegible]	29	31	4774144	8786783	29	31	4926767	8702124	29
32	4622646	[illegible]	28	32	4776700	8785394	28	32	4929298	8700691	28
33	4625225	[illegible]	27	33	4779255	8784004	27	33	4931829	8699256	27
34	4627804	[illegible]	26	34	4781810	8782613	26	34	4934359	8697821	26
35	4630382	[illegible]	25	35	4784364	8781222	25	35	4936889	8696386	25
36	4632960	[illegible]	24	36	4786919	8779830	24	36	4939419	8694949	24
37	4635538	[illegible]	23	37	4789472	8778437	23	37	4941948	8693512	23
38	4638115	8859339	22	38	4792026	8777043	22	38	4944476	8692074	22
39	4640692	8857989	21	39	4794579	8775649	21	39	4947005	8690636	21
40	4643269	8856639	20	40	4797131	8774254	20	40	4949532	8689196	20
41	4645845	8855288	19	41	4799683	8772858	19	41	4952060	8687756	19
42	4648420	8853936	18	42	4802235	8771462	18	42	4954587	8686315	18
43	4650996	8852584	17	43	4804786	8770064	17	43	4957113	8684874	17
44	4653571	8851230	16	44	4807337	8768666	16	44	4959639	8683431	16
45	4656145	8849876	15	45	4809888	8767268	15	45	4962165	8681988	15
46	4658719	8848522	14	46	4812438	8765868	14	46	4964690	8680544	14
47	4661293	8847166	13	47	4814987	8764468	13	47	4967215	8679100	13
48	4663866	8845810	12	48	4817537	8763067	12	48	4969740	8677655	12
49	4666439	8844453	11	49	4820086	8761665	11	49	4972264	8676209	11
50	4669012	8843095	10	50	4822634	8760263	10	50	4974787	8674762	10
51	4671584	8841736	9	51	4825182	8758859	9	51	4977310	8673314	9
52	4674156	8840377	8	52	4827730	8757455	8	52	4979833	8671866	8
53	4676727	8839017	7	53	4830277	8756051	7	53	4982355	8670417	7
54	4679298	8837656	6	54	4832824	8754645	6	54	4984877	8668967	6
55	4681869	8836295	5	55	4835370	8753239	5	55	4987399	8667517	5
56	4684439	8834933	4	56	4837916	8751832	4	56	4989920	8666066	4
57	4687009	8833569	3	57	4840462	8750425	3	57	4992441	8664614	3
58	4689578	8832206	2	58	4843007	8749016	2	58	4994961	8663161	2
59	4692147	8830841	1	59	4845552	8747607	1	59	4997481	8661708	1
60	4694716	8829476	0	60	4848096	8746197	0	60	5000000	8660254	0
′	Cosine	Sine	′	′	Cosine	Sine	′	′	Cosine	Sine	′
Deg. 62.				Deg. 61.				Deg. 60.			

30 Deg.				31 Deg.				32 Deg.			
′	Sine	Cosine	′	′	Sine	Cosine	′	′	Sine	Cosine	′
0	5000000	8660254	60	0	5150381	8571673	60	0	5299193	8480481	60
1	5002519	8658799	59	1	5152874	8570174	59	1	5301659	8478939	59
2	5005037	8657344	58	2	5155367	8568675	58	2	5304125	8477397	58
3	5007556	8655887	57	3	5157859	8567175	57	3	5306591	8475853	57
4	5010073	8654430	56	4	5160351	8565674	56	4	5309057	8474309	56
5	5012591	8652973	55	5	5162842	8564173	55	5	5311521	8472765	55
6	5015107	8651514	54	6	5165333	8562671	54	6	5313986	8471219	54
7	5017624	8650055	53	7	5167824	8561168	53	7	5316450	8469673	53
8	5020140	8648595	52	8	5170314	8559664	52	8	5318913	8468126	52
9	5022655	8647134	51	9	5172804	8558160	51	9	5321376	8466579	51
10	5025170	8645673	50	10	5175293	8556655	50	10	5323839	8465030	50
11	5027685	8644211	49	11	5177782	8555149	49	11	5326301	8463481	49
12	5030199	8642748	48	12	5180270	8553643	48	12	5328763	8461932	48
13	5032713	8641284	47	13	5182758	8552135	47	13	5331224	8460381	47
14	5035227	8639820	46	14	5185246	8550627	46	14	5333685	8458830	46
15	5037740	8638355	45	15	5187733	8549119	45	15	5336145	8457278	45
16	5040252	8636889	44	16	5190219	[illegible]	44	16	5338605	8455726	44
17	5042765	8635423	43	17	5192705	[illegible]	43	17	5341065	8454172	43
18	5045276	8633956	42	18	[illegible]	[illegible]	42	18	5343523	8452618	42
19	5047788	8632488	41	19	5197676	[illegible]	41	19	5345982	8451064	41
20	5050298	8631019	40	20	5200161	[illegible]	40	20	5348440	8449508	40
21	5052809	8629549	39	21	5202646	8540051	39	21	[illegible]	[illegible]	39
22	5055319	8628079	38	22	[illegible]	8538538	38	22	5353355	8446395	38
23	5057828	8626608	37	23	5207613	8537023	37	23	5355812	8444838	37
24	5060338	8625137	36	24	5210096	8535508	36	24	5358268	8443279	36
25	5062846	8623664	35	25	5212579	8533992	35	25	5360724	8441720	35
26	5065355	8622191	34	26	5215061	8532475	34	26	5363179	8440161	34
27	5067863	8620717	33	27	5217543	8530957	33	27	5365634	8438600	33
28	5070370	8619243	32	28	5220024	8529440	32	28	5368089	8437039	32
29	5072877	8617768	31	29	[illegible]	8527921	31	29	5370543	8435477	31
30	5075384	8616292	30	30	5224986	8526402	30	30	5372996	8433914	30
31	5077890	8614815	29	31	5227466	8524881	29	31	5375449	8432351	29
32	5080396	8613337	28	32	5229945	8523360	28	32	5377902	8430787	28
33	5082901	8611859	27	33	5232424	8521839	27	33	5380354	8429222	27
34	5085406	8610380	26	34	[illegible]	8520316	26	34	5382806	8427657	26
35	5087910	8608901	25	35	5237381	8518793	25	35	5385257	8426091	25
36	5090414	8607420	24	36	5239859	8517269	24	36	5387708	8424524	24
37	5092918	8605939	23	37	5242336	8515745	23	37	[illegible]	[illegible]	23
38	5095421	8604457	22	38	5244813	8514219	22	38	5392608	8421388	22
39	5097924	8602975	21	39	5247290	8512693	21	39	5395058	8419819	21
40	5100426	8601491	20	40	5249766	8511167	20	40	5397507	8418249	20
41	5102928	8600007	19	41	5252241	8509639	19	41	5399955	8416679	19
42	5105429	8598523	18	42	5254717	8508111	18	42	5402403	8415108	18
43	5107930	8597037	17	43	[illegible]	8506582	17	43	5404851	8413536	17
44	5110431	8595551	16	44	5259665	8505053	16	44	5407298	8411963	16
45	5112931	8594064	15	45	5262139	8503522	15	45	5409745	8410390	15
46	5115431	8592576	14	46	5264613	8501991	14	46	5412191	8408816	14
47	5117930	8591088	13	47	[illegible]	8500459	13	47	5414637	8407241	13
48	5120429	8589599	12	48	5269558	8498927	12	48	5417082	8405666	12
49	5122927	8588109	11	49	5272030	8497394	11	49	5419527	8404090	11
50	5125425	8586619	10	50	5274502	8495860	10	50	5421971	8402513	10
51	5127923	8585127	9	51	5276973	8494325	9	51	5424415	8400936	9
52	5130420	8583635	8	52	5279443	8492790	8	52	5426859	8399357	8
53	5132916	8582143	7	53	[illegible]	8491254	7	53	5429302	8397778	7
54	5135413	8580649	6	54	[illegible]	8489717	6	54	5431744	8396199	6
55	5137908	8579155	5	55	5286853	8488179	5	55	5434187	8394618	5
56	5140404	8577660	4	56	[illegible]	8486641	4	56	5436628	8393037	4
57	5142899	8576164	3	57	5291790	[illegible]	3	57	5439069	8391455	3
58	5145393	8574668	2	58	5294258	8483562	2	58	5441510	8389873	2
59	5147887	8573171	1	59	5296726	8482022	1	59	5443951	8388290	1
60	5150381	8571673	0	60	5299193	8480481	0	60	5446390	8386706	0
′	Cosine	Sine	′	′	Cosine	Sine	′	′	Cosine	Sine	′
	Deg. 59.				Deg. 58.				Deg. 57.		

33 Deg.			
′	Sine	Cosine	′
0	[illegible]	[illegible]	60
1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58
3	[illegible]	[illegible]	57
4	[illegible]	[illegible]	56
5	[illegible]	[illegible]	55
6	[illegible]	[illegible]	54
7	[illegible]	[illegible]	53
8	[illegible]	[illegible]	52
9	[illegible]	[illegible]	51
10	[illegible]	[illegible]	50
11	[illegible]	[illegible]	49
12	[illegible]	[illegible]	48
13	[illegible]	[illegible]	47
14	[illegible]	[illegible]	46
15	[illegible]	[illegible]	45
16	[illegible]	[illegible]	44
17	[illegible]	[illegible]	43
18	[illegible]	[illegible]	42
19	[illegible]	[illegible]	41
20	[illegible]	[illegible]	40
21	[illegible]	[illegible]	39
22	[illegible]	[illegible]	38
23	[illegible]	[illegible]	37
24	[illegible]	[illegible]	36
25	[illegible]	[illegible]	35
26	[illegible]	[illegible]	34
27	[illegible]	[illegible]	33
28	[illegible]	[illegible]	32
29	5516944	8340463	31
30	[illegible]	[illegible]	30
31	[illegible]	[illegible]	29
32	[illegible]	[illegible]	28
33	5526645	8334038	27
34	5529069	8332430	26
35	[illegible]	[illegible]	25
36	[illegible]	[illegible]	24
37	[illegible]	[illegible]	23
38	[illegible]	[illegible]	22
39	[illegible]	[illegible]	21
40	[illegible]	[illegible]	20
41	[illegible]	[illegible]	19
42	[illegible]	[illegible]	18
43	[illegible]	[illegible]	17
44	5553283	8316312	16
45	[illegible]	[illegible]	15
46	5558121	[illegible]	14
47	[illegible]	[illegible]	13
48	[illegible]	[illegible]	12
49	[illegible]	[illegible]	11
50	[illegible]	[illegible]	10
51	[illegible]	[illegible]	9
52	[illegible]	[illegible]	8
53	[illegible]	[illegible]	7
54	[illegible]	[illegible]	6
55	[illegible]	[illegible]	5
56	[illegible]	[illegible]	4
57	[illegible]	[illegible]	3
58	5587105	[illegible]	2
59	[illegible]	[illegible]	1
60	[illegible]	[illegible]	0
′	Cosine	Sine	′
Deg. 56.			

34 Deg.			
′	Sine	Cosine	′
0	[illegible]	[illegible]	60
1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58
3	[illegible]	[illegible]	57
4	[illegible]	[illegible]	56
5	[illegible]	[illegible]	55
6	[illegible]	[illegible]	54
7	[illegible]	[illegible]	53
8	[illegible]	[illegible]	52
9	[illegible]	[illegible]	51
10	[illegible]	[illegible]	50
11	[illegible]	[illegible]	49
12	[illegible]	[illegible]	48
13	[illegible]	[illegible]	47
14	[illegible]	[illegible]	46
15	[illegible]	[illegible]	45
16	[illegible]	[illegible]	44
17	[illegible]	[illegible]	43
18	[illegible]	[illegible]	42
19	[illegible]	[illegible]	41
20	[illegible]	[illegible]	40
21	[illegible]	[illegible]	39
22	[illegible]	[illegible]	38
23	[illegible]	[illegible]	37
24	[illegible]	[illegible]	36
25	[illegible]	[illegible]	35
26	[illegible]	[illegible]	34
27	[illegible]	[illegible]	33
28	[illegible]	[illegible]	32
29	5661665	8242909	31
30	[illegible]	[illegible]	30
31	[illegible]	[illegible]	29
32	[illegible]	[illegible]	28
33	5671252	8236316	27
34	5673648	8234666	26
35	[illegible]	[illegible]	25
36	[illegible]	[illegible]	24
37	[illegible]	[illegible]	23
38	[illegible]	[illegible]	22
39	[illegible]	[illegible]	21
40	[illegible]	[illegible]	20
41	[illegible]	[illegible]	19
42	[illegible]	[illegible]	18
43	[illegible]	[illegible]	17
44	5697577	8218127	16
45	[illegible]	[illegible]	15
46	[illegible]	[illegible]	14
47	[illegible]	[illegible]	13
48	[illegible]	[illegible]	12
49	[illegible]	[illegible]	11
50	[illegible]	[illegible]	10
51	[illegible]	[illegible]	9
52	[illegible]	[illegible]	8
53	[illegible]	[illegible]	7
54	[illegible]	[illegible]	6
55	[illegible]	[illegible]	5
56	[illegible]	[illegible]	4
57	[illegible]	[illegible]	3
58	[illegible]	[illegible]	2
59	[illegible]	[illegible]	1
60	[illegible]	[illegible]	0
′	Cosine	Sine	′
Deg. 55.			

35 Deg.			
′	Sine	Cosine	′
0	[illegible]	8191520	60
1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58
3	[illegible]	[illegible]	57
4	[illegible]	[illegible]	56
5	[illegible]	[illegible]	55
6	[illegible]	[illegible]	54
7	[illegible]	[illegible]	53
8	[illegible]	[illegible]	52
9	[illegible]	[illegible]	51
10	[illegible]	[illegible]	50
11	[illegible]	[illegible]	49
12	[illegible]	[illegible]	48
13	[illegible]	[illegible]	47
14	[illegible]	[illegible]	46
15	[illegible]	[illegible]	45
16	[illegible]	[illegible]	44
17	[illegible]	[illegible]	43
18	[illegible]	[illegible]	42
19	[illegible]	[illegible]	41
20	[illegible]	[illegible]	40
21	[illegible]	[illegible]	39
22	[illegible]	[illegible]	38
23	[illegible]	[illegible]	37
24	[illegible]	[illegible]	36
25	[illegible]	[illegible]	35
26	[illegible]	[illegible]	34
27	[illegible]	[illegible]	33
28	[illegible]	[illegible]	32
29	5864661	8142844	31
30	[illegible]	[illegible]	30
31	[illegible]	[illegible]	29
32	[illegible]	[illegible]	28
33	5814132	8136084	27
34	5816408	8134393	26
35	[illegible]	[illegible]	25
36	[illegible]	[illegible]	24
37	[illegible]	[illegible]	23
38	[illegible]	[illegible]	22
39	[illegible]	[illegible]	21
40	[illegible]	[illegible]	20
41	[illegible]	[illegible]	19
42	[illegible]	[illegible]	18
43	[illegible]	[illegible]	17
44	5840136	8117439	16
45	[illegible]	[illegible]	15
46	[illegible]	[illegible]	14
47	[illegible]	[illegible]	13
48	[illegible]	[illegible]	12
49	[illegible]	[illegible]	11
50	[illegible]	[illegible]	10
51	[illegible]	[illegible]	9
52	[illegible]	[illegible]	8
53	[illegible]	[illegible]	7
54	[illegible]	[illegible]	6
55	[illegible]	[illegible]	5
56	[illegible]	[illegible]	4
57	[illegible]	[illegible]	3
58	[illegible]	[illegible]	2
59	[illegible]	[illegible]	1
60	[illegible]	[illegible]	0
′	Cosine	Sine	′
Deg. 54.			

36 Deg.			
′	Sine	Cosine	′
0	5877853	8090170	60
1	5880206	8088460	59
2	5882558	8086749	58
3	5884910	8085037	57
4	5887262	8083325	56
5	5889613	8081612	55
6	5891964	[illegible]	54
7	5894314	8078185	53
8	5896663	8076470	52
9	5899012	8074754	51
10	5901361	8073038	50
11	5903709	[illegible]	49
12	[illegible]	[illegible]	48
13	[illegible]	[illegible]	47
14	5910750	[illegible]	46
15	[illegible]	[illegible]	45
16	5915442	[illegible]	44
17	[illegible]	[illegible]	43
18	5920132	8059283	42
19	5922476	8057560	41
20	[illegible]	[illegible]	40
21	[illegible]	[illegible]	39
22	[illegible]	[illegible]	38
23	[illegible]	[illegible]	37
24	5934189	8048938	36
25	5936530	8047211	35
26	[illegible]	[illegible]	34
27	[illegible]	[illegible]	33
28	5943550	8042028	32
29	[illegible]	[illegible]	31
30	[illegible]	[illegible]	30
31	[illegible]	[illegible]	29
32	[illegible]	[illegible]	28
33	[illegible]	[illegible]	27
34	[illegible]	[illegible]	26
35	[illegible]	[illegible]	25
36	[illegible]	[illegible]	24
37	[illegible]	[illegible]	23
38	[illegible]	[illegible]	22
39	[illegible]	[illegible]	21
40	[illegible]	[illegible]	20
41	[illegible]	[illegible]	19
42	[illegible]	[illegible]	18
43	[illegible]	[illegible]	17
44	[illegible]	[illegible]	16
45	[illegible]	[illegible]	15
46	5985577	8010797	14
47	[illegible]	[illegible]	13
48	[illegible]	[illegible]	12
49	[illegible]	[illegible]	11
50	[illegible]	[illegible]	10
51	5997221	8002083	9
52	[illegible]	[illegible]	8
53	[illegible]	[illegible]	7
54	[illegible]	[illegible]	6
55	[illegible]	[illegible]	5
56	6008854	7993352	4
57	[illegible]	[illegible]	3
58	[illegible]	[illegible]	2
59	[illegible]	[illegible]	1
60	[illegible]	[illegible]	0
′	Cosine	Sine	′
		Deg. 53.	

37 Deg.			
′	Sine	Cosine	′
0	6018150	[illegible]	60
1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58
3	6025117	7981100	57
4	6027439	7979347	56
5	[illegible]	[illegible]	55
6	[illegible]	[illegible]	54
7	6034400	7974084	53
8	6036719	7972329	52
9	6039038	7970572	51
10	6041350	[illegible]	50
11	[illegible]	[illegible]	49
12	[illegible]	[illegible]	48
13	[illegible]	[illegible]	47
14	[illegible]	[illegible]	46
15	[illegible]	[illegible]	45
16	6055255	[illegible]	44
17	[illegible]	[illegible]	43
18	6059884	7954735	42
19	6062198	7952972	41
20	[illegible]	[illegible]	40
21	[illegible]	[illegible]	39
22	[illegible]	[illegible]	38
23	[illegible]	[illegible]	37
24	6073758	7944146	36
25	6076069	7942379	35
26	[illegible]	[illegible]	34
27	[illegible]	[illegible]	33
28	6082998	7937074	32
29	[illegible]	[illegible]	31
30	[illegible]	[illegible]	30
31	[illegible]	[illegible]	29
32	[illegible]	[illegible]	28
33	[illegible]	[illegible]	27
34	[illegible]	[illegible]	26
35	[illegible]	[illegible]	25
36	[illegible]	[illegible]	24
37	[illegible]	[illegible]	23
38	[illegible]	[illegible]	22
39	[illegible]	[illegible]	21
40	[illegible]	[illegible]	20
41	[illegible]	[illegible]	19
42	[illegible]	[illegible]	18
43	[illegible]	[illegible]	17
44	[illegible]	[illegible]	16
45	[illegible]	[illegible]	15
46	6124473	7905115	14
47	[illegible]	[illegible]	13
48	[illegible]	[illegible]	12
49	[illegible]	[illegible]	11
50	[illegible]	[illegible]	10
51	6135964	7896198	9
52	[illegible]	[illegible]	8
53	[illegible]	[illegible]	7
54	[illegible]	[illegible]	6
55	[illegible]	[illegible]	5
56	6147442	7887266	4
57	[illegible]	[illegible]	3
58	[illegible]	[illegible]	2
59	[illegible]	[illegible]	1
60	[illegible]	[illegible]	0
′	Cosine	Sine	′
		Deg. 52.	

38 Deg.			
′	Sine	Cosine	′
0	[illegible]	[illegible]	60
1	[illegible]	[illegible]	59
2	[illegible]	[illegible]	58
3	6163489	7874732	57
4	6165780	7872939	56
5	[illegible]	[illegible]	55
6	[illegible]	[illegible]	54
7	6172648	7867555	53
8	6174936	7865759	52
9	6177224	7863963	51
10	[illegible]	[illegible]	50
11	[illegible]	[illegible]	49
12	[illegible]	[illegible]	48
13	[illegible]	[illegible]	47
14	[illegible]	[illegible]	46
15	[illegible]	[illegible]	45
16	[illegible]	[illegible]	44
17	[illegible]	[illegible]	43
18	6197790	7847764	42
19	6200073	7845961	41
20	[illegible]	[illegible]	40
21	[illegible]	[illegible]	39
22	[illegible]	[illegible]	38
23	[illegible]	[illegible]	37
24	6211478	7836935	36
25	6213757	7835127	35
26	[illegible]	[illegible]	34
27	[illegible]	[illegible]	33
28	6220592	7829702	32
29	[illegible]	[illegible]	31
30	[illegible]	[illegible]	30
31	[illegible]	[illegible]	29
32	[illegible]	[illegible]	28
33	[illegible]	[illegible]	27
34	[illegible]	[illegible]	26
35	[illegible]	[illegible]	25
36	[illegible]	[illegible]	24
37	[illegible]	[illegible]	23
38	[illegible]	[illegible]	22
39	[illegible]	[illegible]	21
40	[illegible]	[illegible]	20
41	[illegible]	[illegible]	19
42	[illegible]	[illegible]	18
43	[illegible]	[illegible]	17
44	[illegible]	[illegible]	16
45	[illegible]	[illegible]	15
46	6261503	[illegible]	14
47	[illegible]	[illegible]	13
48	[illegible]	[illegible]	12
49	[illegible]	[illegible]	11
50	[illegible]	[illegible]	10
51	6272837	[illegible]	9
52	[illegible]	[illegible]	8
53	[illegible]	[illegible]	7
54	[illegible]	[illegible]	6
55	[illegible]	[illegible]	5
56	6284157	[illegible]	4
57	[illegible]	[illegible]	3
58	[illegible]	[illegible]	2
59	[illegible]	[illegible]	1
60	[illegible]	[illegible]	0
′	Cosine	Sine	′
		Deg. 51.	

39 Deg.				40 Deg.				41 Deg.			
′	Sine	Cosine	′	′	Sine	Cosine	′	′	Sine	Cosine	′
0	[illegible]	[illegible]	60	0	6427876	7660444	60	0	6560590	7547096	60
1	[illegible]	[illegible]	59	1	6430104	7658574	59	1	6562785	7545187	59
2	[illegible]	[illegible]	58	2	6432332	7656704	58	2	6564980	7543278	58
3	[illegible]	[illegible]	57	3	6434559	7654832	57	3	6567174	7541368	57
4	[illegible]	[illegible]	56	4	6436785	7652960	56	4	6569367	7539457	56
5	[illegible]	[illegible]	55	5	6439011	7651087	55	5	6571560	7537546	55
6	6306758	7760464	54	6	6441236	7649214	54	6	6573752	7535634	54
7	6309015	7758629	53	7	6443461	7647340	53	7	6575944	7533721	53
8	6311272	7756794	52	8	6445685	7645465	52	8	6578135	7531808	52
9	6313528	7754957	51	9	6447909	7643590	51	9	6580326	7529894	51
10	[illegible]	[illegible]	50	10	[illegible]	7641714	50	10	6582516	7527980	50
11	[illegible]	[illegible]	49	11	[illegible]	[illegible]	49	11	6584706	7526065	49
12	[illegible]	[illegible]	48	12	[illegible]	[illegible]	48	12	[illegible]	7524149	48
13	[illegible]	[illegible]	47	13	[illegible]	[illegible]	47	13	[illegible]	7522233	47
14	[illegible]	[illegible]	46	14	[illegible]	[illegible]	46	14	6591271	7520316	46
15	[illegible]	[illegible]	45	15	[illegible]	[illegible]	45	15	6593458	7518398	45
16	[illegible]	[illegible]	44	16	6463460	7630445	44	16	6595645	7516480	44
17	[illegible]	[illegible]	43	17	[illegible]	[illegible]	43	17	6597831	7514561	43
18	[illegible]	[illegible]	42	18	[illegible]	[illegible]	42	18	6600017	7512641	42
19	[illegible]	[illegible]	41	19	[illegible]	[illegible]	41	19	6602202	7510721	41
20	[illegible]	[illegible]	40	20	[illegible]	[illegible]	40	20	6604386	7508800	40
21	[illegible]	[illegible]	39	21	[illegible]	[illegible]	39	21	[illegible]	[illegible]	39
22	[illegible]	[illegible]	38	22	[illegible]	[illegible]	38	22	[illegible]	[illegible]	38
23	[illegible]	[illegible]	37	23	[illegible]	[illegible]	37	23	[illegible]	[illegible]	37
24	[illegible]	[illegible]	36	24	[illegible]	[illegible]	36	24	[illegible]	[illegible]	36
25	[illegible]	[illegible]	35	25	[illegible]	[illegible]	35	25	[illegible]	[illegible]	35
26	[illegible]	[illegible]	34	26	[illegible]	[illegible]	34	26	[illegible]	[illegible]	34
27	[illegible]	[illegible]	33	27	[illegible]	[illegible]	33	27	[illegible]	[illegible]	33
28	[illegible]	[illegible]	32	28	[illegible]	[illegible]	32	28	[illegible]	[illegible]	32
29	[illegible]	[illegible]	31	29	[illegible]	[illegible]	31	29	[illegible]	[illegible]	31
30	[illegible]	[illegible]	30	30	[illegible]	[illegible]	30	30	[illegible]	[illegible]	30
31	[illegible]	[illegible]	29	31	[illegible]	[illegible]	29	31	[illegible]	[illegible]	29
32	[illegible]	[illegible]	28	32	[illegible]	[illegible]	28	32	[illegible]	[illegible]	28
33	[illegible]	[illegible]	27	33	[illegible]	[illegible]	27	33	[illegible]	[illegible]	27
34	[illegible]	[illegible]	26	34	[illegible]	[illegible]	26	34	[illegible]	[illegible]	26
35	[illegible]	[illegible]	25	35	[illegible]	[illegible]	25	35	[illegible]	[illegible]	25
36	[illegible]	[illegible]	24	36	[illegible]	[illegible]	24	36	[illegible]	[illegible]	24
37	[illegible]	[illegible]	23	37	[illegible]	[illegible]	23	37	[illegible]	[illegible]	23
38	[illegible]	[illegible]	22	38	[illegible]	[illegible]	22	38	[illegible]	[illegible]	22
39	[illegible]	[illegible]	21	39	[illegible]	[illegible]	21	39	[illegible]	[illegible]	21
40	6383201	[illegible]	20	40	[illegible]	[illegible]	20	40	[illegible]	[illegible]	20
41	[illegible]	[illegible]	19	41	[illegible]	[illegible]	19	41	[illegible]	[illegible]	19
42	[illegible]	[illegible]	18	42	[illegible]	[illegible]	18	42	[illegible]	[illegible]	18
43	[illegible]	[illegible]	17	43	[illegible]	[illegible]	17	43	[illegible]	[illegible]	17
44	[illegible]	[illegible]	16	44	[illegible]	[illegible]	16	44	[illegible]	[illegible]	16
45	[illegible]	[illegible]	15	45	[illegible]	[illegible]	15	45	[illegible]	[illegible]	15
46	[illegible]	[illegible]	14	46	[illegible]	[illegible]	14	46	[illegible]	[illegible]	14
47	[illegible]	[illegible]	13	47	[illegible]	[illegible]	13	47	[illegible]	[illegible]	13
48	6401097	[illegible]	12	48	[illegible]	[illegible]	12	48	[illegible]	[illegible]	12
49	6403332	[illegible]	11	49	[illegible]	[illegible]	11	49	[illegible]	[illegible]	11
50	6405566	[illegible]	10	50	[illegible]	[illegible]	10	50	[illegible]	[illegible]	10
51	6407799	7677246	9	51	6540810	[illegible]	9	51	[illegible]	[illegible]	9
52	6410032	7675382	8	52	6543010	[illegible]	8	52	[illegible]	[illegible]	8
53	6412264	7673517	7	53	[illegible]	[illegible]	7	53	[illegible]	[illegible]	7
54	6414496	7671652	6	54	[illegible]	7555535	6	54	[illegible]	[illegible]	6
55	6416728	7669785	5	55	[illegible]	[illegible]	5	55	[illegible]	[illegible]	5
56	6418958	7667918	4	56	6551804	7554724	4	56	[illegible]	[illegible]	4
57	6421189	[illegible]	3	57	6554002	7552818	3	57	[illegible]	[illegible]	3
58	6423418	[illegible]	2	58	[illegible]	7550911	2	58	[illegible]	[illegible]	2
59	6425647	[illegible]	1	59	[illegible]	7549004	1	59	[illegible]	[illegible]	1
60	6427876	[illegible]	0	60	[illegible]	7547096	0	60	[illegible]	[illegible]	0
′	Cosine	Sine	′	′	Cosine	Sine	′	′	Cosine	Sine	′
Deg. 50.				Deg. 49.				Deg. 48.			

	42 Deg.				43 Deg.				44 Deg.		
′	Sine	Cosine	′	′	Sine	Cosine	′	′	Sine	Cosine	′
0	6691306	7431448	60	0	6819984	7313537	60	0	6946584	7193398	60
1	6693468	7429502	59	1	6822111	7311553	59	1	6948676	7191377	59
2	6695628	7427554	58	2	6824237	7309568	58	2	6950767	7189355	58
3	6697789	7425606	57	3	6826363	7307583	57	3	6952858	7187333	57
4	6699948	7423658	56	4	6828489	7305597	56	4	6954949	7185310	56
5	6702108	7421708	55	5	6830613	7303610	55	5	6957039	7183287	55
6	6704266	7419758	54	6	6832738	7301623	54	6	6959128	7181263	54
7	6706424	7417808	53	7	6834861	7299635	53	7	6961217	7179238	53
8	6708582	7415857	52	8	6836984	7297646	52	8	[illegible]	[illegible]	52
9	6710739	7413905	51	9	6839107	7295657	51	9	[illegible]	7175187	51
10	6712895	7411953	50	10	6841229	7293668	50	10	6967479	7173161	50
11	6715051	7410000	49	11	6843350	7291677	49	11	[illegible]	[illegible]	49
12	6717205	7408046	48	12	6845471	[illegible]	48	12	[illegible]	[illegible]	48
13	6719361	7406092	47	13	6847591	7287695	47	13	[illegible]	7167078	47
14	6721515	7404137	46	14	6849711	7285703	46	14	[illegible]	[illegible]	46
15	6723668	7402181	45	15	6851830	7283710	45	15	[illegible]	7163010	45
16	6725821	7400225	44	16	6853948	7281716	44	16	[illegible]	[illegible]	44
17	6727973	7398268	43	17	6856066	7279722	43	17	[illegible]	[illegible]	43
18	6730125	7396311	42	18	6858184	7277728	42	18	[illegible]	[illegible]	42
19	6732276	7394353	41	19	6860300	7275732	41	19	[illegible]	[illegible]	41
20	6734427	7392394	40	20	6862416	7273736	40	20	[illegible]	[illegible]	40
21	6736577	7390435	39	21	6864532	7271740	39	21	[illegible]	[illegible]	39
22	6738727	7388475	38	22	6866647	7269743	38	22	[illegible]	[illegible]	38
23	6740876	7386515	37	23	6868761	7267745	37	23	[illegible]	[illegible]	37
24	6743024	7384553	36	24	6870875	7265747	36	24	[illegible]	[illegible]	36
25	6745172	7382592	35	25	6872988	7263748	35	25	[illegible]	[illegible]	35
26	6747319	7380629	34	26	6875101	7261748	34	26	[illegible]	[illegible]	34
27	6749466	7378666	33	27	6877213	7259748	33	27	[illegible]	[illegible]	33
28	6751612	7376703	32	28	6879325	7257747	32	28	[illegible]	[illegible]	32
29	6753757	7374738	31	29	6881435	7255746	31	29	[illegible]	7134543	31
30	6755902	7372773	30	30	6883546	7253744	30	30	[illegible]	[illegible]	30
31	6758046	7370808	29	31	6885655	7251741	29	31	[illegible]	[illegible]	29
32	6760190	7368842	28	32	6887765	7249738	28	32	[illegible]	[illegible]	28
33	6762333	7366875	27	33	6889873	7247734	27	33	7015314	7126385	27
34	6764476	7364908	26	34	6891981	7245729	26	34	7017387	7124344	26
35	6766618	7362940	25	35	6894089	7243724	25	35	[illegible]	7122303	25
36	6768760	7360971	24	36	6896195	7241719	24	36	[illegible]	7120260	24
37	6770901	7359002	23	37	6898302	7239712	23	37	7023601	7118218	23
38	6773041	7357032	22	38	6900407	7237705	22	38	7025672	[illegible]	22
39	6775181	7355061	21	39	6902512	7235698	21	39	[illegible]	[illegible]	21
40	6777320	7353090	20	40	6904617	7233690	20	40	[illegible]	[illegible]	20
41	6779459	7351118	19	41	6906721	7231681	19	41	7031870	[illegible]	19
42	6781597	7349146	18	42	6908824	7229671	18	42	7033947	7107995	18
43	6783734	7347173	17	43	6910927	7227661	17	43	7036014	[illegible]	17
44	6785871	7345199	16	44	6913029	7225651	16	44	[illegible]	7103901	16
45	6788007	7343225	15	45	[illegible]	[illegible]	15	45	7040147	[illegible]	15
46	6790143	7341250	14	46	6917232	7221628	14	46	7042213	7099800	14
47	6792278	7339275	13	47	6919332	7219615	13	47	[illegible]	7097757	13
48	6794413	7337299	12	48	6921432	7217602	12	48	7046342	7095707	12
49	6796547	7335322	11	49	6923531	7215589	11	49	7048406	7093657	11
50	6798681	7333345	10	50	6925630	7213574	10	50	7050469	7091607	10
51	6800813	7331367	9	51	6927728	7211559	9	51	[illegible]	[illegible]	9
52	6802946	7329388	8	52	6929825	7209544	8	52	7054594	7087504	8
53	6805078	7327409	7	53	6931922	7207528	7	53	[illegible]	7085451	7
54	6807209	7325429	6	54	6934018	7205511	6	54	[illegible]	7083398	6
55	6809339	7323449	5	55	6936114	7203494	5	55	7060776	7081345	5
56	6811469	7321467	4	56	6938209	7201476	4	56	7062835	7079291	4
57	6813599	7319486	3	57	6940304	7199457	3	57	[illegible]	[illegible]	3
58	6815728	7317503	2	58	6942398	7197438	2	58	[illegible]	[illegible]	2
59	6817856	7315521	1	59	6944491	7195418	1	59	[illegible]	[illegible]	1
60	6819984	7313537	0	60	6946584	7193398	0	60	7071068	[illegible]	0
′	Cosine	Sine	′	′	Cosine	Sine	′	′	Cosine	Sine	′
	Deg. 47.				Deg. 46.				Deg. 45.		

TANGENTS.

′	0°	1°	2°	3°	4°	5°	6°	′
0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59
2	·0005818	·0180370	·0355033	·0529912	·0705115	·0880749	·1056925	58
3	·0008727	·0183280	·0357945	·0532829	·0708038	·0883681	·1059865	57
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56
5	·0014544	·0189100	·0363771	·0538663	·0713885	·0889544	·1065750	55
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54
7	·0020362	·0194920	·0369596	·0544498	·0719733	·0895408	·1071634	53
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49
12	·0034907	·0209470	·0384161	·0559087	·0734354	·0910071	·1086348	48
13	·0037816	·0212380	·0387074	·0562005	·0737279	·0913004	·1089291	47
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46
15	·0043634	·0218201	·0392901	·0567841	·0743128	·0918871	·1095178	45
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44
17	·0049451	·0224021	·0398728	·0573678	·0748979	·0924738	·1101066	43
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37
24	·0069814	·0244395	·0419124	·0594109	·0769458	·0945278	·1121680	36
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
31	·0090178	·0264770	·0439524	·0614546	·0789914	·0965826	·1142303	29
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	·0098905	·0273503	·0448268	·0623306	·0798726	·0974635	·1151144	26
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25
36	·0104724	·0279325	·0454097	·0629147	·0804581	·0980509	·1157039	24
37	·0107633	·0282236	·0457012	·0632067	·0807509	·0983446	·1159987	23
38	·0110542	·0285148	·0459927	·0634988	·0810437	·0986383	·1162936	22
39	·0113451	·0288059	·0462842	·0637908	·0813365	·0989320	·1165884	21
40	0·0116361	0·0290970	0·0465757	0·0640829	0·0816293	0·0992257	0·1168832	20
41	·0119270	·0293882	·0468673	·0643750	·0819221	·0995194	·1171781	19
42	·0122179	·0296793	·0471588	·0646671	·0822150	·0998133	·1174730	18
43	·0125088	·0299705	·0474503	·0649592	·0825078	·1001071	·1177679	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	·0130907	·0305528	·0480334	·0655435	·0830936	·1006947	·1183578	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	·0148364	·0322998	·0497829	·0672965	·0848512	·1024580	·1201279	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	·0157093	·0331734	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	·0160002	·0334646	·0509495	·0684654	·0860233	·1036340	·1213085	5
56	·0162912	·0337558	·0512411	·0687577	·0863163	·1039280	·1216030	4
57	·0165821	·0340471	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
58	·0168731	·0343383	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	·0171641	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	0·0174551	0·0349208	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
′	89°	88°	87°	86°	85°	84°	83°	′

CO-TANGENTS.

TANGENTS.

′	7°	8°	9°	10°	11°	12°	13°	′
0	0·1227846	0·1405408	0·1583844	0·1763270	[illegible]	0·2125566	[illegible]	60
1	[illegible]	·1408375	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59
2	·1233752	·1411342	·1589809	.1769269	·1949841	·2131647	·2314811	58
3	·1236705	·1414308	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57
4	·1239658	·1417276	·1595774	·1775270	·1955881	·2137730	·2320941	56
5	·1242012	·1420243	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55
6	·1245566	·1423211	·1601740	·1781271	·1961922	·2143814	·2327073	54
7	·1248520	·1426179	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53
8	·1251474	·1429147	·1607708	·1787274	·1967964	·2149900	·2333207	52
9	·1254429	·1432115	·1610692	·1790276	·1970986	·2152944	·2336274	51
10	[illegible]	0·1435084	0·1613677	[illegible]	[illegible]	[illegible]	[illegible]	50
11	·1260339	·1438053	·1616662	·1796281	·1977031	·2159032	·2342410	49
12	·1263294	·1441022	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48
13	·1266249	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47
14	·1269205	·1446961	·1625618	·1805291	·1980100	·2168167	·2351617	46
15	·1272161	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45
16	·1275117	·1452901	·1631590	·1811299	·1992148	·2174259	·2357758	44
17	·1278073	·1455872	·1634576	·1814303	·1995172	·2177306	·2360829	43
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	·1283986	·1461813	·1640550	·1820313	·2001222	·2183400	·2366971	41
20	[illegible]	0·1464784	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
21	·1289900	·1467756	·1646525	·1826324	·2007274	·2189496	·2373116	39
22	·1292858	·1470727	·1649513	·1829330	·2010300	·2192544	·2376189	38
23	·1295815	·1473699	·1652501	·1832337	·2013327	·2195593	·2379262	37
24	·1298773	·1476672	·1655489	·1835343	·2016354	·2198643	·2382336	36
25	·1301731	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35
26	[illegible]	[illegible]	[illegible]	·1841358	[illegible]	[illegible]	[illegible]	34
27	·1307648	·1485590	·1664456	·1844365	·2025437	·2207793	·239 560	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	·1313566	·1491530	·1670436	·1850382	·2031494	·2213895	·2397711	31
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
31	·1319484	·1497484	·1676417	·1856399	·2037552	·2219099	·2403864	29
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25
36	·1334285	·1512358	·1691373	·1871449	·2052705	·2235265	·2410255	24
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	·1343168	·1521285	·1700351	·1880483	·2061801	·2244429	·2428494	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
46	·1363903	·1542125	·1721309	·1901573	·2083038	·2265827	·2450068	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	·1372793	·1551061	·1730296	·1910617	·2092145	·2275003	·2459320	11
50	0·1375757	0·1554040	0·1733292	0·1913632	0·2095181	0·2278063	0·2462405	10
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	0·1405408	[illegible]	[illegible]	0·1943803	[illegible]	[illegible]	[illegible]	0
′	82°	81°	80°	79°	78°	77°	76°	′

CO-TANGENTS.

TANGENTS.

′	14°	15°	16°	17°	18°	19°	20°	′
0	[illegible]	[illegible]	[illegible]	0·3057307	0·3249197	0·3443276	0·3639702	60
1	[illegible]	[illegible]	·2870602	·3060488	·3252413	·3446530	·3642997	59
2	·2499460	·2685728	·2873751	·3063670	·3255630	·3449785	·3646292	58
3	·2502551	·2688847	·2876900	·3066852	·3258848	·3453040	·3649588	57
4	[illegible]	[illegible]	[illegible]	·3070034	·3262066	[illegible]	·3652885	56
5	[illegible]	[illegible]	[illegible]	·3073218	·3265284	·3459553	·3656182	55
6	[illegible]	[illegible]	[illegible]	·3076402	·3268504	·3462810	·3659480	54
7	·2514919	·2701328	·2889503	·3079586	·3271724	·3466068	·3662779	53
8	·2518012	·2704449	·2892655	·3082771	·3274944	·3469327	·3666079	52
9	·2521106	·2707571	·2895808	·3085957	·3278165	·3472586	·3669379	51
10	[illegible]	[illegible]	[illegible]	0·3089143	0·3281387	0·3475846	0·3672680	50
11	·2527294	·2713817	·2902114	·3092330	·3284610	·3479107	·3675981	49
12	·2530389	·2716940	·2905269	·3095517	·3287833	·3482368	·3679284	48
13	·2533484	·2720064	·2908423	·3098705	·3291056	·3485630	·3682587	47
14	[illegible]	·2723188	·2911578	·3101893	·3294281	·3488893	·3685890	46
15	·2539676	·2726313	·2914734	·3105083	·3297505	·3492156	·3689195	45
16	·2542773	·2729438	·2917890	·3108272	·3300731	·3495420	·3692500	44
17	·2545870	·2732564	·2921047	·3111462	·3303957	·3498685	·3695806	43
18	[illegible]	[illegible]	[illegible]	·3114653	·3307184	·3501950	·3699112	42
19	[illegible]	[illegible]	[illegible]	·3117845	·3310411	·3505216	·3702420	41
20	[illegible]	[illegible]	[illegible]	0·3121036	0·3313639	0·3508483	0·3705728	40
21	[illegible]	[illegible]	[illegible]	·3124229	·3316868	·3511750	·3709036	39
22	·2561363	·2748201	·2936839	·3127422	·3320097	·3515018	·3712346	38
23	·2564463	·2751330	·2939999	·3130616	·3323327	·3518287	·3715656	37
24	·2567564	·2754459	·2943160	·3133810	·3326557	·3521556	·3718967	36
25	[illegible]	[illegible]	·2946321	·3137005	·3329788	·3524825	·3722278	35
26	·2573766	·2760719	·2949483	·3140200	·3333020	·3528096	·3725590	34
27	·2576868	·2763850	·2952645	·3143396	·3336252	·3531368	·3728903	33
28	·2579970	·2766981	·2955808	·3146593	·3339485	·3534640	·3732217	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0·3541186	[illegible]	30
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28
33	·2595488	·2782646	·2971630	·3162585	·3355660	·3551010	·3748797	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	·2601699	·2788915	·2977962	·3168986	·3362134	·3557562	·3755433	25
36	·2604805	·2792050	·2981129	·3172187	·3365372	·3560840	·3758753	24
37	·2607911	·2795186	·2984297	·3175389	·3368610	·3564118	·3762073	23
38	·2611018	·2798322	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	·2614126	·2801459	·2990634	·3181794	·3375090	·3570676	·3768716	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	·2620342	·2807735	·2996973	·3188202	·3381571	·3577237	·3775361	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	·2814012	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	·2629670	·2817152	·3006486	·3197819	·3391299	·3587083	·3785335	16
45	·2632780	·2820292	·3009658	·3201025	·3394543	·3590367	·3788661	15
46	·2635891	·2823432	·3012831	·3204232	·3397787	·3593651	·3791988	14
47	·2639002	·2826573	·3016004	·3207440	·3401032	·3596936	·3795315	13
48	·2642114	·2829715	·3019178	·3210649	·3404278	·3600222	·3798644	12
49	·2645226	·2832857	·3022352	·3213858	·3407524	·3603508	·3801973	11
50	0·2648339	0·2835999	0·3025527	0·3217067	0·3410771	0·3606795	0·3805302	10
51	·2651452	·2839143	[illegible]	·3220278	[illegible]	·3610082	[illegible]	9
52	·2654566	·2842286	·3031879	·3223489	·3417267	·3613371	·3811964	8
53	·2657680	·2845430	·3035055	·3226700	·3420516	·3616660	·3815296	7
54	·2660794	·2848575	·3038232	·3229912	·3423765	·3619949	·3818629	6
55	·2663909	·2851720	·3041410	·3233125	·3427015	[illegible]	[illegible]	5
56	·2667025	·2854866	·3044588	·3236338	·3430266	·3626531	·3825296	4
57	·2670141	·2858012	·3047767	·3239552	·3433518	·3629823	·3828631	3
58	·2673257	·2861159	·3050946	·3242766	·3436770	·3633115	·3831967	2
59	·2676374	·2864306	·3054126	·3245981	·3440023	·3636408	·3835303	1
60	0·2679492	0·2867454	0·3057307	0·3249197	0·3443276	0·3639702	0·3838640	0
′	75°	74°	73°	72°	71°	70°	69°	′

CO-TANGENTS.

	TANGENTS.							
′	21°	22°	23°	24°	25°	26°	27°	′
0	[illegible]	0·4040262	0.4244748	0·4452287	0·4663077	0·4877326	[illegible]	60
1	·3841978	·4043646	[illegible]	·4455773	·4666618	·4880927	[illegible]	59
2	[illegible]	·4047031	[illegible]	·4459260	·4670161	[illegible]	[illegible]	58
3	[illegible]	·4050417	·4255051	[illegible]	·4673705	·4888133	[illegible]	57
4	·3851996	·4053804	·4258487	·4466236	·4677250	·4891737	[illegible]	56
5	·3855337	·4057191	·4261924	[illegible]	·4680796	·4895343	[illegible]	55
6	·3858679	·4060579	·4265361	·4473216	·4684342	·4898949	[illegible]	54
7	[illegible]	[illegible]	·4268800	[illegible]	·4687890	·4902557	[illegible]	53
8	·3865364	·4067358	·4272239	[illegible]	·4691439	·4906166	[illegible]	52
9	·3868708	·4070748	[illegible]	·4483693	·4694988	[illegible]	[illegible]	51
10	0·3872053	0·4074139	[illegible]	0·4487187	[illegible]	0·4913386	0·5131950	50
11	·3875398	·4077531	[illegible]	·4490682	·4702090	[illegible]	·5135625	49
12	·3878744	·4080924	·4286005	·4494178	·4705643	·4920610	[illegible]	48
13	·3882091	·4084318	[illegible]	·4497675	·4709196	·4924224	[illegible]	47
14	[illegible]	·4087713	·4292891	·4501173	·4712751	4927838	[illegible]	46
15	[illegible]	·4091108	[illegible]	·4504672	·4716306	·4931454	[illegible]	45
16	·3892136	·4094504	[illegible]	·4508171	·4719863	·4935071	[illegible]	44
17	[illegible]	[illegible]	·4303232	[illegible]	·4723420	[illegible]	[illegible]	43
18	·3898837	[illegible]	·4306680	·4515173	·4726978	·4942308	[illegible]	42
19	·3902189	·4104697	·4310129	·4518676	·4730538	·4945928	[illegible]	41
20	[illegible]	[illegible]	[illegible]	0·4522179	0·4734098	0·4949549	[illegible]	40
21	[illegible]	·4111497	·4317030	·4525683	[illegible]	·4953171	[illegible]	39
22	·3912247	·4114898	·4320481	[illegible]	·4741222	·4956795	[illegible]	38
23	[illegible]	·4118300	·4323933	·4532694	[illegible]	·4960418	[illegible]	37
24	·3918957	·4121703	·4327386	·4536201	·4748349	[illegible]	[illegible]	36
25	·3922313	[illegible]	[illegible]	·4539709	·4751914	[illegible]	[illegible]	35
26	·3925670	[illegible]	·4334295	·4543218	·4755481	·4971207	[illegible]	34
27	·3929027	[illegible]	·4337751	·4546728	·4759048	[illegible]	[illegible]	33
28	[illegible]	[illegible]	[illegible]	·4550238	[illegible]	[illegible]	[illegible]	32
29	·3935745	[illegible]	·4344665	·4553750	·4766185	[illegible]	[illegible]	31
30	0·3939105	0·4142136	[illegible]	[illegible]	0·4769755	[illegible]	[illegible]	30
31	·3942465	·4145544	[illegible]	[illegible]	·4773326	[illegible]	[illegible]	29
32	·3945827	·4148953	[illegible]	·4564290	[illegible]	[illegible]	[illegible]	28
33	·3949189	·4152363	[illegible]	·4567806	[illegible]	[illegible]	[illegible]	27
34	·3952552	·4155774	[illegible]	·4571322	[illegible]	[illegible]	[illegible]	26
35	[illegible]	·4159186	·4365429	[illegible]	[illegible]	[illegible]	[illegible]	25
36	·3959280	·4162598	[illegible]	·4578357	·4791197	[illegible]	[illegible]	24
37	·3962645	·4166012	[illegible]	·4581877	·4794774	[illegible]	[illegible]	23
38	[illegible]	[illegible]	·4375823	·4585397	·4798352	[illegible]	[illegible]	22
39	[illegible]	[illegible]	[illegible]	·4588918	·4801932	[illegible]	[illegible]	21
40	[illegible]	0·4176257	0·4382756	[illegible]	0·4805512	[illegible]	[illegible]	20
41	·3976114	[illegible]	[illegible]	·4595962	·4809093	·5025832	[illegible]	19
42	·3979483	·4183091	[illegible]	·4599486	[illegible]	[illegible]	[illegible]	18
43	·3982853	·4186506	·4393163	– ·4603011	[illegible]	·5033121	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	·4819842	·5036768	[illegible]	16
45	[illegible]	·4193348	[illegible]	·4610063	·4823427	·5040415	[illegible]	15
46	·3992968	·4196769	[illegible]	·4613591	·4827014	·5044063	[illegible]	14
47	[illegible]	·4200190	[illegible]	·4617119	·4830601	·5047713	[illegible]	13
48	[illegible]	·4203613	·4410526	[illegible]	·4834189	[illegible]	[illegible]	12
49	·4003089	[illegible]	·4414001	·4624179	·4837778	·5055015	[illegible]	11
50	[illegible]	0·4210460	[illegible]	0·4627710	0·4841368	[illegible]	0·5270839	10
51	·4009841	·4213885	·4420954	·4631243	[illegible]	·5062322	[illegible]	9
52	·4013218	[illegible]	·4424432	·4634776	[illegible]	[illegible]	[illegible]	8
53	·4016596	·4220738	·4427910	·4638310	·4852145	[illegible]	·5291004	7
54	·4019974	[illegible]	·4431390	[illegible]	·4855739	[illegible]	·5294727	6
55	·4023354	·4227591	·4434871	[illegible]	·4859334	[illegible]	·5298452	5
56	·4026734	·4231023	·4438352	[illegible]	[illegible]	[illegible]	·5302178	4
57	·4030115	·4234453	·4441834	·4652457	[illegible]	[illegible]	[illegible]	3
58	[illegible]	·4237884	·4445318	·4655996	·4870126	[illegible]	[illegible]	2
59	[illegible]	[illegible]	·4448802	·4659536	·4873726	[illegible]	[illegible]	1
60	[illegible]	0·4244748	0·4452287	0·4663077	0·4877326	[illegible]	[illegible]	0
′	68°	67°	66°	65°	64°	63°	62°	′
	CO-TANGENTS.							

TANGENTS.

′	28°	29°	30°	31°	32°	33°	34°	′
0	[illegible]	[illegible]	0·5773503	0·6008606	0·6248694	0·6494076	0·6745085	60
1	[illegible]	[illegible]	[illegible]	·6012566	·6252739	·6498212	·6749318	59
2	·5324559	·5550698	·5781262	·6016527	·6256786	·6502350	·6753553	58
3	·5328293	·5554504	·5785144	·6020490	·6260834	·6506490	·6757790	57
4	·5332029	·5558311	·5789027	·6024454	·6264884	·6510631	·6762028	56
5	·5335765	·5562119	·5792912	·6028419	·6268935	·6514774	·6766268	55
6	·5339503	·5565929	·5796797	·6032386	·6272988	·6518918	·6770509	54
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	·6774752	53
8	·5346981	·5573551	·5804573	·6040323	·6281098	·6527211	·6778997	52
9	·5350723	·5577364	·5808462	·6044294	·6285155	·6531360	·6783243	51
10	0·5354465	0·5581179	0·5812353	0·6048266	0·6289214	0·6535511	0·6787492	50
11	[illegible]	[illegible]	[illegible]	·6052240	[illegible]	[illegible]	·6791741	49
12	·5361953	·5588811	·5820139	·6056215	·6297336	·6543817	·6795993	48
13	·5365699	·5592629	·5824034	·6060192	·6301399	·6547972	·6800246	47
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	·6552129	·6804501	46
15	·5373194	·5600269	·5831828	·6068149	·6309530	·6556287	·6808758	45
16	·5376943	·5604091	·5835726	·6072130	·6313598	·6560447	·6813016	44
17	·5380694	·5607914	·5839627	·6076112	·6317667	·6564609	·6817276	43
18	·5384445	·5611738	·5843528	·6080095	·6321738	·6568772	·6821537	42
19	·5388198	·5615564	·5847431	·6084080	·6325810	·6572937	·6825801	41
20	0·5391952	0·5619391	0·5851335	0·6088067	0·6329883	0·6577103	0·6830066	40
21	·5395707	·5623219	·5855241	·6092054	·6333959	·6581271	·6834333	39
22	·5399464	·5627048	·5859148	·6096043	·6338035	·6585441	·6838601	38
23	[illegible]	·5630879	·5863056	·6100034	·6342113	·6589612	·6842871	37
24	·5406980	·5634710	·5866965	·6104026	·6346193	·6593785	·6847143	36
25	·5410740	·5638543	·5870876	·6108019	·6350274	·6597960	·6851416	35
26	·5414501	·5642378	·5874788	·6112014	·6354357	·6602136	·6855692	34
27	·5418263	·5646213	·5878702	·6116011	·6358441	·6606313	·6859969	33
28	·5422027	·5650050	·5882616	·6120008	·6362527	·6610492	·6864247	32
29	·5425791	·5653888	·5886533	·6124007	·6366614	·6614673	·6868528	31
30	0·5429557	0·5657728	0·5890450	0·6128008	0·6370703	0·6618856	0·6872810	30
31	·5433324	·5661568	·5894369	·6132010	·6374793	·6623040	·6877093	29
32	·5437092	·5665410	·5898289	·6136013	·6378885	·6627225	·6881379	28
33	·5440862	·5669254	·5902211	·6140018	·6382978	·6631413	·6885666	27
34	·5444632	·5673098	·5906134	·6144024	·6387073	·6635601	·6889955	26
35	·5448404	·5676944	·5910058	·6148032	·6391169	·6639792	·6894246	25
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	·5455951	·5684639	·5917910	·6156052	·6399366	·6648178	·6902832	23
38	·5459727	·5688488	·5921839	·6160064	·6403467	·6652373	·6907128	22
39	·5463503	·5692339	·5925768	·6164077	·6407569	·6656570	·6911425	21
40	0·5467281	0·5696191	0·5929699	0·6168092	0·6411673	0·6660769	0·6915725	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	·5478621	·5707755	·5941501	·6180145	·6423994	·6673374	·6928613	17
44	·5482404	·5711612	·5945437	·6184166	·6428105	·6677580	·6932939	16
45	·5486188	·5715471	·5949375	·6188188	·6432216	·6681786	·6937247	15
46	·5489973	·5719331	·5953314	·6192211	·6436329	·6685995	·6941557	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	·5497547	·5727054	·5961196	·6200263	·6444560	·6694417	·6950181	12
49	·5501335	·5730918	·5965140	·6204291	·6448678	·6698630	·6954496	11
50	0·5505125	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	[illegible]	[illegible]	[illegible]	·6212351	[illegible]	[illegible]	[illegible]	9
52	·5512708	·5742516	·5976978	·6216383	·6461041	·6711280	·6967451	8
53	·5516502	·5746385	·5980926	·6220417	·6465165	·6715500	·6971773	7
54	·5520297	·5750255	·5984877	·6224452	·6469290	·6719721	·6976097	6
55	·5524093	·5754126	·5988828	·6228488	·6473417	·6723944	·6980422	5
56	·5527890	·5757999	·5992781	·6232527	·6477546	·6728169	·6984749	4
57	·5531088	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
58	·5535488	·5765748	·6000691	·6240607	·6485808	·6736624	·6993409	2
59	·5539288	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	0·5543091	0·5773503	0·6008606	0·6248694	0·6494076	0·6745085	0·7002075	0
′	61°	60°	59°	58°	57°	56°	55°	′

CO-TANGENTS.

TANGENTS.

′	35°	36°	37°	38°	39°	40°	41°	′
0	0·7002075	0·7265425	0·7535541	0·7812856	[illegible]	0·8390996	[illegible]	60
1	[illegible]	·7269871	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59
2	·7010749	·7274318	·7544666	·7822229	·8107478	·8400915	·8703087	58
3	·7015089	·7278767	·7549232	·7826919	·8112300	·8405878	·8708200	57
4	·7019430	·7283218	·7553799	·7831611	·8117124	·8410844	·8713316	56
5	·7023773	·7287671	·7558369	·7836305	·8121951	·8415812	·8718435	55
6	·7028118	·7292125	·7562941	·7841002	·8126780	·8420782	·8723556	54
7	·7032464	·7296582	·7567514	·7845700	·8131611	·8425755	·8728680	53
8	·7036813	·7301041	·7572090	·7850400	·8136444	·8430730	·8733806	52
9	·7041163	·7305501	·7576668	·7855103	·8141280	·8435708	·8738935	51
10	0·7045515	[illegible]	0·7581248	[illegible]	[illegible]	[illegible]	[illegible]	50
11	·7049869	·7314428	·7585829	·7864515	·8150958	·8445670	·8749201	49
12	·7054224	·7318894	·7590413	·7869224	·8155801	·8450655	[illegible]	48
13	·7058581	·7323362	·7594999	·7873935	·8160646	·8455643	·8759478	47
14	·7062940	·7327832	·7599587	·7878649	·8165493	·8460633	·8764020	46
15	·7067301	·7332303	·7604177	·7883364	·8170343	·8465625	·8769765	45
16	·7071664	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44
17	·7076028	·7341253	·7613363	·7892802	·8180049	·8475617	·8780062	43
18	·7080395	·7345730	·7617959	·7897524	[illegible]	[illegible]	[illegible]	42
19	·7084763	·7350210	·7622557	·7902248	·8189764	·8485619	·8790370	41
20	0·7089133	0·7354691	0·7627157	0·7906975	0·8194625	0·8490024	0·8795528	40
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	·7097878	·7363660	·7636363	·7916434	·8204354	·8500640	·8805852	38
23	·7102253	·7368147	·7640969	·7921167	·8209222	·8505653	·8811017	37
24	·7106630	·7372636	·7645577	·7925902	·8214093	·8510667	·8816186	36
25	·7111009	·7377127	·7650188	·7930640	·8218965	·8515684	·8821357	35
26	·7115390	·7381620	·7654800	·7935379	·8223840	·8520704	·8826531	34
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33
28	·7124157	·7390611	·7664031	·7944865	·8233597	·8530750	·8836886	32
29	·7128543	·7395110	·7668649	·7949611	·8238479	·8535777	·8842068	31
30	0·7132931	0·7399611	0·7673270	0·7954359	0·8243364	0·8540807	0·8847253	30
31	·7137320	·7404113	·7677893	·7959110	·8248251	·8545839	·8852440	29
32	·7141712	·7408618	·7682517	·7963862	·8253140	·8550873	·8857630	28
33	·7146106	·7413124	·7687144	·7968617	·8258031	·8555910	·8862822	27
34	·7150501	·7417633	·7691773	·7973374	·8262925	·8560950	·8868017	26
35	·7154898	·7422143	·7696404	·7978134	·8267821	·8565992	·8873215	25
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	·7185729	·7453770	·7728878	·8011511	·8302160	·8601357	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	·7194554	·7462824	·7738176	·8021067	·8311992	·8611484	[illegible]	16
45	·7198970	·7467354	·7742827	·8025849	·8316912	·8616551	[illegible]	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	·7216650	·7485404	·7761455	·8044997	·8336625	·8636846	·8946268	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	·7225502	·7494575	·7770782	·8054584	·8346481	·8647009	·8956747	9
52	·7229930	·7499119	·7775448	·8059382	·8351418	·8652094	·8961991	8
53	·7234361	·7503665	·7780117	·8064181	·8356357	·8657181	·8967238	7
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	·7243227	·7512762	·7789460	·8073787	·8360242	·8667365	·8977739	5
56	·7247663	·7517314	·7794135	·8078593	·8371188	·8672460	·8982994	4
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	·8993512	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	0·7265425	0·7535541	[illegible]	0·8097840	[illegible]	[illegible]	0·9004040	0
′	54°	53°	52°	51°	50°	49°	48°	′

CO-TANGENTS.

TANGENTS.

′	42°	43°	44°	45°	46°	47°	48°	′
0	[illegible]	0·9325151	0·9656888	1·0000000	1·0355303	1·0723687	1·1106125	60
1	[illegible]	[illegible]	·9662511	[illegible]	[illegible]	[illegible]	1·1112624	59
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1119127	58
3	·9019854	·9341479	·9673767	1·0017469	1·0373404	1·0742467	1·1125635	57
4	·9025131	·9346928	·9679399	1·0023298	1·0379445	1·0748734	1·1132146	56
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·0755006	[illegible]	55
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·0761282	[illegible]	54
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53
8	·9046267	·9368753	·9701962	1·0046651	1·0403645	1·0773845	1·1158235	52
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48
13	·9072748	·9396101	·9730236	1·0075918	1·0433977	1·0805321	1·1190941	47
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45
16	[illegible]	[illegible]	[illegible]	[illegible]	1·0452221	1·0824254	1·1210616	44
17	·9093984	·9418033	·9752914	1·0099394	1·0458310	1·0830573	1·1217183	43
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
21	[illegible]	[illegible]	[illegible]	[illegible]	1·0482702	[illegible]	[illegible]	39
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37
24	·9131255	·9456530	·9792724	1·0140610	1·0501034	1·0874918	1·1263271	36
25	[illegible]	[illegible]	[illegible]	1·0146512	[illegible]	[illegible]	[illegible]	35
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
27	·9147270	·9473074	·9809833	1·0158326	1·0519401	1·0893984	1·1283088	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29
32	·9174020	·9500709	·9838415	1·0187923	1·0550087	1·0925840	1·1316203	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	·9190104	·9517326	·9855603	1·0205723	1·0568544	1·0945002	1·1336124	25
36	·9195471	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	·9200841	·9528420	·9867079	1·0217608	1·0580867	1·0957797	1·1349427	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	·9211590	·9539526	·9878567	1·0229506	1·0593206	1·0970609	1·1362747	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	·9222350	·9550644	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	·9227734	·9556208	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	·9233122	·9561774	·9901584	1·0253346	1·0617929	1·0996281	1·1389411	17
44	·9238512	·9567344	·9907346	1·0259315	1·0624119	1·1002709	1·1396126	16
45	·9243905	·9572917	·9913112	1·0265287	1·0630313	1·1009141	1·1402815	15
46	·9249301	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	·9254700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	·9260102	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	·9265506	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
50	0·9270914	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	·9276324	·9606421	·9947777	[illegible]	[illegible]	[illegible]	[illegible]	9
52	·9281738	·9612016	·9953566	[illegible]	[illegible]	[illegible]	[illegible]	8
53	·9287154	·9617614	·9959358	[illegible]	[illegible]	[illegible]	[illegible]	7
54	·9292573	·9623215	·9965154	[illegible]	[illegible]	[illegible]	[illegible]	6
55	·9297996	·9628819	·9970953	1·0325208	[illegible]	[illegible]	[illegible]	5
56	·9303421	·9634427	·9976756	1·0331220	1·0698702	1·1086171	[illegible]	4
57	·9308849	·9640037	·9982562	1·0337235	[illegible]	[illegible]	[illegible]	3
58	·9314280	·9645651	·9988371	1·0343254	1·0711187	[illegible]	[illegible]	2
59	·9319714	·9651268	·9994184	1·0349277	1·0717435	[illegible]	[illegible]	1
60	0·9325151	0·9656888	1·0000000	1·0355303	1·0723687	1·1106125	[illegible]	0
′	47°	46°	45°	44°	43°	42°	41°	′

CO-TANGENTS.

TANGENTS.

′	49°	50°	51°	52°	53°	54°	55°	′
0	1·1503684	1·1917536	1·2348972	1·2799416	1·3270448	[illegible]	1·4281480	60
1	1·1510445	1·1924579	[illegible]	[illegible]	[illegible]	1·3772242	1·4290326	59
2	1·1517210	1·1931626	1·2363672	1·2814776	[illegible]	1·3780672	[illegible]	58
3	1·1523979	1·1938679	1·2371030	1·2822465	[illegible]	1·3789108	1·4308039	57
4	1·1530754	1·1945736	1·2378393	1·2830160	[illegible]	[illegible]	1·4316906	56
5	1·1537532	1·1952799	1·2385762	1·2837860	[illegible]	1·3806001	1·4325781	55
6	1·1544316	1·1959866	1·2393136	1·2845566	1·3318750	1·3814458	1·4334664	54
7	1·1551104	1·1966938	1·2400515	1·2853277	1·3326822	1·3822922	1·4343554	53
8	1·1557896	1·1974015	1·2407900	[illegible]	1·3334900	1·3831392	1·4352451	52
9	1·1564693	[illegible]	1·2415290	[illegible]	1·3342984	[illegible]	1·4361356	51
10	1·1571495	1·1988184	1·2422685	1·2876447	[illegible]	[illegible]	1·4370268	50
11	1·1578301	1·1995276	1·2430086	1·2884182	1·3359172	[illegible]	1·4379187	49
12	1·1585112	1·2002373	1·2437492	1·2891922	1·3367276	[illegible]	[illegible]	48
13	1·1591927	1·2009475	1·2444903	[illegible]	[illegible]	[illegible]	1·4397049	47
14	1·1598747	1·2016581	1·2452320	1·2907421	1·3383502	[illegible]	[illegible]	46
15	1·1605571	1·2023693	1·2459742	1·2915179	1·3391624	[illegible]	1·4414940	45
16	1·1612400	1·2030810	1·2467169	1·2922943	1·3399753	[illegible]	1·4423897	44
17	1·1619234	1·2037932	1·2474602	1·2930713	1·3407888	[illegible]	[illegible]	43
18	1·1626073	1·2045058	1·2482040	1·2938488	1·3416029	[illegible]	[illegible]	42
19	1·1632916	1·2052190	1·2489484	[illegible]	1·3424177	1·3925019	[illegible]	41
20	1·1639763	1·2059327	[illegible]	1·2954057	1·3432331	[illegible]	[illegible]	40
21	1·1646615	1·2066468	1·2504388	1·2961850	[illegible]	1·3942131	[illegible]	39
22	1·1653472	1·2073615	1·2511848	1·2969649	[illegible]	1·3950698	[illegible]	38
23	1·1660334	1·2080767	1·2519313	1·2977454	1·3456832	1·3959272	[illegible]	37
24	1·1667200	1·2087924	1·2526784	1·2985265	1·3465011	[illegible]	1·4495825	36
25	1·1674071	1·2095085	[illegible]	1·2993081	[illegible]	1·3976440	1·4504850	35
26	1·1680947	1·2102252	1·2541742	1·3000904	1·3481390	1·3985034	[illegible]	34
27	1·1687827	1·2109424	1·2549229	1·3008733	1·3489589	1·3993637	1·4522923	33
28	1·1694712	[illegible]	[illegible]	1·3016567	[illegible]	1·4002245	[illegible]	32
29	1·1701601	1·2123783	1·2564219	[illegible]	[illegible]	[illegible]	1·4541027	31
30	1·1708496	1·2130970	1·2571723	1·3032254	1·3514224	1·4019483	1·4550090	30
31	1·1715395	[illegible]	1·2579232	1·3040106	[illegible]	1·4028113	[illegible]	29
32	1·1722298	1·2145359	[illegible]	1·3047964	[illegible]	1·4036749	1·4568240	28
33	1·1729207	[illegible]	[illegible]	1·3055828	[illegible]	[illegible]	1·4577326	27
34	1·1736120	1·2159769	1·2601792	1·3063699	[illegible]	1·4054044	1·4586420	26
35	1·1743038	1·2166982	1·2609323	1·3071575	[illegible]	1·4062702	1·4595522	25
36	1·1749960	1·2174199	1·2616860	[illegible]	1·3563670	1·4071367	1·4604632	24
37	1·1756888	[illegible]	1·2624402	1·3087345	[illegible]	1·4080039	1·4613749	23
38	1·1763820	[illegible]	1·2631950	1·3095239	1·3580204	1·4088718	1·4622874	22
39	1·1770756	[illegible]	1·2639503	[illegible]	1·3588481	1·4097405	1·4632007	21
40	1·1777698	[illegible]	1·2647062	[illegible]	[illegible]	1·4106098	[illegible]	20
41	1·1784644	[illegible]	1·2654626	[illegible]	[illegible]	1·4114799	1·4650296	19
42	1·1791595	[illegible]	1·2662196	1·3126876	1·3613350	[illegible]	[illegible]	18
43	1·1798551	1·2224860	1·2669772	1·3134801	1·3621653	[illegible]	1·4668010	17
44	1·1805512	[illegible]	1·2677353	1·3142731	[illegible]	[illegible]	1·4677788	16
45	1·1812477	1·2239389	[illegible]	[illegible]	1·3638279	1·4149673	1·4686967	15
46	1·1819447	1·2246658	1·2692532	1·3158610	1·3646602	[illegible]	1·4696155	14
47	1·1826422	1·2253932	1·2700130	1·3166559	[illegible]	[illegible]	1·4705350	13
48	1·1833402	1·2261211	1·2707733	1·3174513	1·3663267	[illegible]	[illegible]	12
49	1·1840387	[illegible]	1·2715342	[illegible]	[illegible]	1·4184662	1·4723764	11
50	1·1847376	1·2275786	1·2722957	[illegible]	1·3679959	[illegible]	1·4732983	10
51	1·1854370	1·2283081	1·2730578	[illegible]	1·3688315	1·4202200	1·4742210	9
52	[illegible]	1·2290381	1·2738204	1·3206393	1·3696678	1·4210979	[illegible]	8
53	1·1868373	1·2297687	1·2745835	1·3214379	1·3705047	1·4219766	[illegible]	7
54	1·1875382	1·2304997	[illegible]	1·3222370	[illegible]	1·4228561	[illegible]	6
55	1·1882395	[illegible]	1·2761116	1·3230368	[illegible]	1·4237362	[illegible]	5
56	1·1889414	1·2319634	1·2768765	1·3238371	1·3730195	1·4246171	1·4788463	4
57	[illegible]	1·2326961	[illegible]	[illegible]	1·3738591	1·4254988	1·4797738	3
58	1·1903465	1·2334292	1·2784079	[illegible]	1·3746994	[illegible]	1·4807021	2
59	1·1910498	1·2341629	[illegible]	1·3262420	1·3755403	1·4272642	[illegible]	1
60	[illegible]	1·2348972	1·2799416	1·3270448	1·3763819	1·4281480	1·4825610	0
′	40°	39°	38°	37°	36°	35°	34°	′

CO-TANGENTS.

TANGENTS.

′	56°	57°	58°	59°	60°	61°	62°	′
0	1·4825610	1·5398650	1·6003345	1·6642795	1·7320508	1·8040478	1·8807265	60
1	1·4834916	[illegible]	1·6013709	1·6653766	1·7332149	1·8052860	[illegible]	59
2	1·4844231	[illegible]	1·6024082	1·6664748	1·7343803	[illegible]	[illegible]	58
3	1·4853554	[illegible]	1·6034465	1·6675741	1·7355468	[illegible]	[illegible]	57
4	1·4862884	1·5437946	1·6044858	1·6686744	1·7367144	[illegible]	[illegible]	56
5	1·4872223	1·5447792	[illegible]	[illegible]	[illegible]	1·8102521	[illegible]	55
6	1·4881570	1·5457647	1·6065672	1·6708782	1·7390533	1·8114969	[illegible]	54
7	[illegible]	1·5467510	1·6076094	1·6719818	1·7402245	1·8127430	[illegible]	53
8	1·4900288	[illegible]	1·6086525	1·6730864	1·7413969	1·8139904	1·8913313	52
9	1·4909659	[illegible]	[illegible]	[illegible]	1·7425705	1·8152391	1·8926635	51
10	1·4919039	1·5497155	[illegible]	[illegible]	1·7437453	1·8164892	1·8639971	50
11	1·4928426	1·5507054	1·6117878	1·6764067	1·7449213	1·8177405	1·8953322	49
12	1·4937822	1·5516963	1·6128349	1·6775156	1·7460984	[illegible]	1·8966688	48
13	1·4947225	1·5526880	1·6138829	1·6786256	[illegible]	[illegible]	1·8980068	47
14	1·4956637	1·5536806	1·6149320	1·6797367	1·7484564	1·8215026	1·8993464	46
15	1·4966058	1·5546741	1·6159820	1·6808489	1·7496371	1·8227593	1·9006874	45
16	1·4975486	[illegible]	[illegible]	[illegible]	[illegible]	1·8240173	1·9020299	44
17	1·4984923	1·5566639	1·6180850	1·6830765	1·7520023	1·8252767	1·9033738	43
18	[illegible]	1·5576601	1·6191380	1·6841919	1·7531866	1·8265374	1·9047193	42
19	1·5003821	1·5586572	1·6201920	1·6853085	1·7543722	1·8277994	1·9060663	41
20	1·5013282	1·5596552	1·6212469	1·6864261	1·7555590	1·8290628	1·9074147	40
21	1·5022751	1·5606542	1·6223029	1·6875449	1·7567470	1·8303275	1·9087647	39
22	1·5032229	1·5616540	1·6233599	1·6886647	1·7579362	1·8315936	[illegible]	38
23	1·5041716	1·5626548	1·6244178	1·6897856	1·7591267	1·8328610	[illegible]	37
24	1·5051210	[illegible]	1·6254768	1·6909077	1·7603183	1·8341297	1·9128236	36
25	1·5060713	1·5646590	[illegible]	[illegible]	[illegible]	1·8353999	[illegible]	35
26	1·5070224	1·5656625	1·6275977	1·6931550	1·7627053	1·8366713	1·9155370	34
27	[illegible]	1·5666669	1·6286597	1·6942804	1·7639007	1·8379442	1·9168960	33
28	[illegible]	1·5676722	[illegible]	[illegible]	[illegible]	1·8392184	1·9182565	32
29	[illegible]	[illegible]	1·6307867	1·6965344	1·7662950	1·8404940	1·9196186	31
30	[illegible]	1·5696856	1·6318517	1·6976631	1·7674940	1·8417709	1·9209821	30
31	1·5117905	1·5706936	1·6329177	1·6987929	1·7686943	1·8430492	1·9223472	29
32	1·5127466	1·5717026	1·6339847	1·6999238	1·7698958	1·8443289	1·9237138	28
33	1·5137036	1·5727126	1·6350528	1·7010559	1·7710985	1·8456099	1·9250819	27
34	1·5146614	1·5737234	1·6361218	1·7021890	1·7723024	1·8468923	1·9264516	26
35	1·5156201	1·5747352	[illegible]	[illegible]	[illegible]	1·8481761	1·9278228	25
36	1·5165796	1·5757479	1·6382630	1·7044587	1·7747141	1·8494613	1·9291956	24
37	1·5175400	1·5767615	[illegible]	[illegible]	[illegible]	1·8507479	1·9305699	23
38	1·5185012	1·5777760	1·6404082	1·7067329	1·7771307	1·8520358	1·9319457	22
39	1·5194632	1·5787915	[illegible]	[illegible]	[illegible]	1·8533252	1·9333231	21
40	1·5204261	1·5798079	1·6425576	1·7090116	1·7795524	[illegible]	1·9347020	20
41	1·5213899	1·5808253	1·6436338	1·7101527	1·7807651	1·8559080	1·9360825	19
42	1·5223545	1·5818436	1·6447111	1·7112949	1·7819790	[illegible]	1·9374645	18
43	1·5233200	1·5828628	[illegible]	[illegible]	[illegible]	1·8584965	1·9388481	17
44	1·5242863	1·5838830	[illegible]	[illegible]	[illegible]	1·8597928	1·9402333	16
45	1·5252535	1·5849041	1·6479490	1·7147283	1·7856285	1·8610905	[illegible]	15
46	1·5262215	1·5859261	1·6490304	1·7158751	[illegible]	1·8623896	1·9430083	14
47	1·5271904	1·5869491	[illegible]	[illegible]	[illegible]	1·8636902	1·9443981	13
48	1·5281602	1·5879731	[illegible]	[illegible]	[illegible]	1·8649921	1·9457896	12
49	1·5291308	1·5889979	1·6522808	1·7193222	1·7905121	[illegible]	1·9471826	11
50	1·5301023	1·5900238	1·6533663	1·7204736	1·7917362	1·8676003	1·9485772	10
51	1·5310746	1·5910505	1·6544529	1·7216261	1·7929616	1·8689065	1·9499733	9
52	1·5320479	1·5920783	[illegible]	[illegible]	[illegible]	1·8702141	1·9513711	8
53	1·5330219	1·5931070	[illegible]	[illegible]	[illegible]	1·8715231	1·9527704	7
54	1·5339969	1·5941366	1·6577189	1·7250905	1·7966454	1·8728336	[illegible]	6
55	1·5349727	1·5951672	1·6588097	[illegible]	[illegible]	1·8741455	1·9555739	5
56	1·5359494	1·5961987	1·6599016	1·7274060	1·7991077	1·8754588	1·9569780	4
57	1·5369270	1·5972312	1·6609945	1·7285654	1·8003408	1·8767736	1·9583837	3
58	1·5379054	1·5982647	1·6620884	[illegible]	[illegible]	1·8780898	1·9597910	2
59	1·5388848	1·5992991	1·6631834	1·7308878	1·8028108	1·8794074	1·9612000	1
60	1·5398650	1·6003345	1·6642795	1·7320508	1·8040478	1·8807265	1·9626105	0
′	33°	32°	31°	30°	29°	28°	27°	′

CO-TANGENTS.

TANGENTS.

′	63°	64°	65°	66°	67°	68°	69°	′
0	1·9626105	2·0503038	2·1445069	2·2460368	2·3558524	2·4750869	[illegible]	[illegible]
1	[illegible]	[illegible]	2·1461366	2·2477962	2·3577590	2·4771612	[illegible]	[illegible]
2	1·9654364	2·0533349	2·1477683	2·2495580	2·3596683	2·4792386	[illegible]	[illegible]
3	1·9668518	2·0548531	[illegible]	[illegible]	[illegible]	2·4813190	[illegible]	[illegible]
4	1·9682688	2·0563732	2·1510378	2·2530885	2·3634946	2·4834023	[illegible]	[illegible]
5	[illegible]	[illegible]	2·1526757	2·2548572	2·3654118	2·4854887	2·6164571	55
6	1·9711077	2·0594187	2·1543156	2·2566283	2·3673316	2·4875781	2·6187411	[illegible]
7	1·9725296	2·0609442	[illegible]	[illegible]	[illegible]	2·4896706	2·6210280	[illegible]
8	1·9739531	2·0624716	2·1576015	2·2601773	2·3711791	2·4917660	2·6233196	[illegible]
9	1·9753782	2·0640008	2·1592476	2·2619554	2·3731068	[illegible]	2·6256141	[illegible]
10	1·9768050	2·0655318	[illegible]	[illegible]	[illegible]	2·4959061	2·6279121	[illegible]
11	1·9782334	2·0670646	2·1625460	2·2655184	2·3769703	2·4980707	2·6302136	[illegible]
12	1·9796635	2·0685994	2·1641983	2·2673035	2·3789060	[illegible]	[illegible]	[illegible]
13	1·9810952	2·0701359	2·1658527	2·2690909	2·3808444	[illegible]	2·6348271	47
14	1·9825286	2·0716743	2·1675091	2·2708807	2·3827855	[illegible]	2·6371392	[illegible]
15	1·9839636	2·0732146	2·1691677	2·2726729	2·3847293	[illegible]	2·6394549	[illegible]
16	1·9854003	2·0747567	2·1708283	2·2744674	2·3866758	[illegible]	2·6417741	44
17	1·9868387	2·0763007	2·1724911	2·2762643	2·3886250	[illegible]	2·6440969	[illegible]
18	1·9882787	2·0778465	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	1·9897204	2·0793942	2·1758229	2·2798653	2·3925316	[illegible]	[illegible]	41
20	1·9911637	2·0809438	2·1774920	2·2816693	2·3944889	2·5171507	[illegible]	[illegible]
21	[illegible]	[illegible]	2·1791631	2·2834758	2·3964490	2·5192863	[illegible]	[illegible]
22	[illegible]	[illegible]	2·1808364	2·2852846	2·3984118	2·5214240	[illegible]	[illegible]
23	1·9955038	2·0856039	[illegible]	[illegible]	[illegible]	2·5235667	[illegible]	[illegible]
24	1·9969539	2·0871610	2·1841894	2·2889096	2·4023457	2·5257117	[illegible]	[illegible]
25	[illegible]	[illegible]	2·1858691	2·2907257	2·4043168	2·5278598	[illegible]	[illegible]
26	1·9998590	2·0902809	2·1875510	2·2925442	2·4062906	[illegible]	[illegible]	[illegible]
27	2·0013142	2·0918437	2·1892349	2·2943651	2·4082672	[illegible]	[illegible]	[illegible]
28	2·0027710	2·0934085	2·1909210	2·2961885	2·4102465	[illegible]	[illegible]	[illegible]
29	2·0042295	2·0949751	2·1926093	2·2980143	2·4122286	2·5364830	[illegible]	[illegible]
30	[illegible]	[illegible]	2·1942997	2·2998425	2·4142136	2·5386479	[illegible]	[illegible]
31	2·0071516	2·0981140	2·1959923	2·3016732	2·4162013	2·5408151	[illegible]	[illegible]
32	2·0086153	2·0996864	[illegible]	[illegible]	[illegible]	2·5429855	[illegible]	[illegible]
33	2·0100806	2·1012607	2·1993840	2·3053420	2·4201851	2·5451591	[illegible]	27
34	[illegible]	[illegible]	2·2010831	2·3071801	2·4221812	2·5473350	[illegible]	[illegible]
35	2·0130164	2·1044150	2·2027843	2·3090206	2·4241801	[illegible]	[illegible]	[illegible]
36	[illegible]	[illegible]	2·2044878	2·3108637	2·4261819	[illegible]	[illegible]	[illegible]
37	2·0159592	2·1075771	2·2061934	2·3127092	2·4281864	[illegible]	[illegible]	[illegible]
38	[illegible]	[illegible]	2·2079012	2·3145571	2·4301938	[illegible]	[illegible]	22
39	2·0189088	2·1107470	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	2·0203862	2·1123348	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	2·0233462	2·1155164	2·2147545	2·3219740	2·4382519	[illegible]	[illegible]	18
43	2·0248289	2·1171101	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	2·0263133	2·1187057	2·2181914	2·3256975	2·4422982	[illegible]	[illegible]	16
45	2·0277994	2·1203034	[illegible]	[illegible]	[illegible]	2·5714957	[illegible]	15
46	2·0292873	2·1219030	[illegible]	[illegible]	[illegible]	2·5737118	[illegible]	14
47	2·0307769	2·1235046	2·2233709	2·3313017	2·4483801	2·5759312	2·7154826	13
48	2·0322683	2·1251082	[illegible]	[illegible]	[illegible]	2·5781539	2·7179204	12
49	[illegible]	[illegible]	2·2268331	2·3350505	2·4524642	[illegible]	2·7203620	11
50	2·0352565	2·1283213	2·2285676	2·3369287	2·4545061	2·5826094	2·7228076	10
51	2·0367532	2·1299308	[illegible]	[illegible]	[illegible]	[illegible]	2·7252569	9
52	2·0382517	2·1315423	[illegible]	[illegible]	[illegible]	2·5870782	2·7277102	8
53	2·0397519	2·1331559	2·2337845	2·3425787	2·4606404	[illegible]	[illegible]	7
54	2·0412540	2·1347714	2·2355280	2·3444672	2·4627030	[illegible]	2·7326284	6
55	2·0427578	2·1363890	[illegible]	[illegible]	[illegible]	[illegible]	2·7350934	5
56	2·0442634	2·1380085	2·2390218	2·3482519	2·4668191	[illegible]	2·7375623	4
57	2·0457708	2·1396301	2·2407721	2·3501481	2·4688816	[illegible]	2·7400352	3
58	2·0472800	2·1412537	2·2425247	2·3520469	2·4709470	[illegible]	2·7425120	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2·7449927	1
60	2·0503038	2·1445069	2·2460368	2·3558524	2·4750869	[illegible]	2·7474774	0
′	26°	25°	24°	23°	22°	21°	20°	′

CO-TANGENTS.

TANGENTS.

′	70°	71°	72°	73°	74°	75°	76°	′
0	2·7474774	[illegible]	3·0776835	3·2708526	3·4874144	3·7320508	4·0107809	60
1	2·7499661	[illegible]	3·0807325	3·2742588	3·4912470	3·7363980	4·0157570	59
2	2·7524588	[illegible]	3·0837869	3·2776715	3·4950874	3·7407546	4·0207446	58
3	2·7549554	[illegible]	3·0868468	3·2810907	3·4989356	3·7451207	[illegible]	57
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3·7494963	4·0307550	56
5	2·7599608	[illegible]	[illegible]	[illegible]	[illegible]	3·7538815	4·0357779	55
6	2·7624695	[illegible]	3·0960596	3·2913876	3·5105273	3·7582763	4·0408125	54
7	2·7649822	[illegible]	3·0991416	3·2948330	3·5144070	[illegible]	4·0458590	53
8	2·7674990	[illegible]	3·1022291	3·2982851	3·5182946	[illegible]	[illegible]	52
9	2·7700199	[illegible]	3·1053223	3·3017438	3·5221902	3·7715185	[illegible]	51
10	2·7725448	[illegible]	3·1084210	3·3052091	3·5260938	3·7759519	4·0610700	50
11	[illegible]	2·9346822	3·1115254	3·3086811	3·5300054	[illegible]	4·0661643	49
12	[illegible]	2·9374807	3·1146353	3·3121598	3·5339251	3·7848481	4·0712707	48
13	2·7801440	2·9402840	3·1177509	3·3156452	3·5378528	3·7893109	4·0763892	47
14	2·7826853	2·9430921	3·1208722	3·3191373	3·5417886	3·7937835	[illegible]	46
15	2·7852307	2·9459050	3·1239991	3·3226362	3·5457325	3·7982661	4·0866627	45
16	2·7877802	2·9487227	3·1271317	3·3261419	3·5496846	3·8027585	4·0918178	44
17	2·7903339	2·9515453	3·1302701	3·3296543	3·5536449	3·8072609	[illegible]	43
18	2·7928917	2·9543727	3·1334141	3·3331736	3·5576133	3·8117733	[illegible]	42
19	2·7954537	2·9572050	3·1365639	3·3366997	3·5615900	3·8162957	[illegible]	41
20	2·7980198	2·9600422	3·1397194	3·3402326	3·5655749	3·8208281	[illegible]	40
21	2·8005901	2·9628842	[illegible]	[illegible]	[illegible]	3·8253707	4·1177784	39
22	2·8031646	2·9657312	3·1460478	3·3473191	3·5735696	3·8299233	4·1230079	38
23	2·8057433	2·9685831	3·1492207	3·3508728	3·5775794	3·8344861	4·1282499	37
24	2·8083263	2·9714399	[illegible]	[illegible]	[illegible]	3·8390591	4·1335046	36
25	2·8109134	2·9743016	3·1555840	3·3580008	3·5856241	[illegible]	[illegible]	35
26	2·8135048	2·9771683	3·1587744	3·3615753	3·5896590	3·8482358	4·1440519	34
27	2·8161004	2·9800400	3·1619706	3·3651568	3·5937024	[illegible]	4·1493446	33
28	2·8187003	[illegible]	3·1651728	3·3687453	3·5977543	3·8574537	4·1546501	32
29	[illegible]	2·9857983	3·1683808	3·3723408	3·6018146	3·8620782	4·1599685	31
30	2·8239129	2·9886850	3·1715948	3·3759434	3·6058835	[illegible]	4·1652998	30
31	2·8265256	2·9915766	3·1748147	3·3795531	3·6099609	3·8713584	4·1706440	29
32	[illegible]	2·9944734	3·1780406	3·3831699	[illegible]	3·8760142	[illegible]	28
33	2·8317639	2·9973751	3·1812724	3·3867938	3·6181415	[illegible]	4·1813713	27
34	2·8343896	3·0002820	3·1845102	3·3904249	3·6222447	3·8853574	4·1867546	26
35	2·8370196	3·0031939	[illegible]	[illegible]	[illegible]	3·8900448	[illegible]	25
36	2·8396539	3·0061109	[illegible]	[illegible]	[illegible]	3·8947429	4·1975606	24
37	2·8422926	[illegible]	[illegible]	[illegible]	[illegible]	3·8994516	4·2029835	23
38	2·8449356	3·0119603	3·1975217	3·4050210	3·6387444	3·9041710	[illegible]	22
39	2·8475831	3·0148926	3·2007897	3·4086882	3·6428911	3·9089011	4·2138690	21
40	2·8502349	3·0178301	3·2040638	3·4123626	3·6470467	3·9136420	[illegible]	20
41	2·8528911	3·0207728	3·2073440	3·4160443	3·6512111	3·9183937	[illegible]	19
42	2·8555517	3·0237207	3·2106304	3·4197333	3·6553844	3·9231563	4·2302977	18
43	2·8582168	3·0266737	3·2139228	3·4234297	3·6595665	3·9279297	4·2358009	17
44	2·8608863	3·0296320	3·2172215	3·4271334	3·6637575	[illegible]	4·2413177	16
45	[illegible]	3·0325954	3·2205263	3·4308446	3·6679575	3·9375094	4·2468482	15
46	2·8662386	3·0355641	3·2238373	3·4345631	3·6721665	3·9423157	4·2523923	14
47	2·8689215	3·0385381	3·2271546	3·4382891	3·6763845	3·9471331	[illegible]	13
48	2·8716088	3·0415173	3·2304780	3·4420226	3·6806115	3·9519615	4·2635218	12
49	[illegible]	3·0445018	3·2338078	3·4457635	3·6848475	3·9568011	4·2691072	11
50	[illegible]	3·0474915	3·2371438	3·4495120	3·6890927	[illegible]	4·2747066	10
51	[illegible]	3·0504866	3·2404860	3·4532679	3·6933469	[illegible]	4·2803199	9
52	[illegible]	[illegible]	3·2438346	3·4570315	3·6976104	3·9713868	4·2859472	8
53	[illegible]	3·0564928	3·2471895	3·4608026	3·7018830	3·9762712	4·2915885	7
54	[illegible]	3·0595038	3·2505508	3·4645813	3·7061648	3·9811669	4·2972440	6
55	2·8905467	3·0625203	3·2539184	3·4683676	3·7104558	3·9860739	4·3029136	5
56	2·8932704	3·0655421	3·2572924	3·4721616	3·7147561	[illegible]	4·3085974	4
57	2·8959986	3·0685694	3·2606728	3·4759632	3·7190658	3·9959223	4·3142955	3
58	2·8987314	3·0716020	3·2640596	3·4797726	3·7233847	4·0008636	4·3200079	2
59	2·9014688	3·0746400	3·2674529	3·4835896	3·7277131	[illegible]	4·3257347	1
60	2·9042109	3·0776835	3·2708526	3·4874144	3·7320508	4·0107809	4·3314759	0
′	19°	18°	17°	16°	15°	14°	13°	′

CO-TANGENTS.

TANGENTS.

′	77°	78°	79°	80°	81°	82°	83°	′
0	4·3314759	4·7046301	5·1445540	[illegible]	6·3137515	[illegible]	[illegible]	60
1	4·3372316	[illegible]	5·1525557	[illegible]	[illegible]	[illegible]	[illegible]	59
2	4·3430018	4·7181256	5·1605813	5·6906394	6·3376126	7·1455308	8·1837041	58
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55
6	4·3662293	4·7453401	5·1929264	5·7297416	6·3858665	7·2066116	8·2635547	54
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53
8	4·3779317	4·7590603	5·2092459	5·7494889	6·4102633	7·2375378	8·3040586	52
9	[illegible]	[illegible]	5·2174128	[illegible]	[illegible]	[illegible]	[illegible]	51
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50
11	4·3955077	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	4·4798636	4·8788248	5·3520626	5·9228322	6·6252258	7·5113178	[illegible]	35
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29
32	4·5231601	4·9298358	5·4130906	5·9971957	6·7178891	[illegible]	[illegible]	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	4·5419608	4·9520125	5·4396592	6·0290247	6·7583826	[illegible]	[illegible]	25
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
38	4·5609111	4·9743817	5·4664812	6·0623967	6·7993565	7·7348028	[illegible]	22
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	4·5736287	4·9894027	5·4845052	6·0844381	6·8269437	7·7703506	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
46	4·6121908	5·0346935	5·5302740	6·1515085	6·9110359	7·8780489	9·1555436	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
′	12°	11°	10°	9°	8°	7°	6°	′

CO-TANGENTS.

TANGENTS.

′	84°	85°	86°	87°	88°	89°	′
0	[illegible]	11·430052	14·300666	19·081137	28·636253	57·289962	60
1	9·5410613	11·468474	14·360696	19·187930	28·877089	58·261174	59
2	[illegible]	11·507154	14·421230	19·295922	29·122005	59·265872	58
3	[illegible]	11·546093	14·482273	19·405133	29·371106	60·305820	57
4	9·6220486	[illegible]	14·543833	19·515584	29·624499	61·382905	56
5	9·6493475	11·624761	14·605916	19·627296	29·882299	62·499154	55
6	9·6768000	[illegible]	14·668529	19·740291	30·144619	[illegible]	54
7	9·7044075	11·704500	14·731679	19·854591	30·411580	64·858008	53
8	9·7321713	11·744779	14·795372	19·970219	30·683307	66·105473	52
9	9·7600927	11·785333	14·859616	20·087199	30·959928	[illegible]	51
10	9·7881732	11·826167	14·924417	20·205553	31·241577	68·750087	50
11	9·8164140	11·867282	14·989784	20·325308	[illegible]	70·153346	49
12	9·8448166	11·908682	15·055723	20·446486	31·820516	71·615070	48
13	9·8733823	11·950370	15·122242	20·569115	32·118099	73·138991	47
14	9·9021125	11·992349	15·189349	20·693220	[illegible]	[illegible]	46
15	9·9310088	12·034622	15·257052	20·818828	32·730264	76·390009	45
16	9·9600724	12·077192	15·325358	20·945966	33·045173	[illegible]	44
17	9·9893050	12·120062	15·394276	21·074664	33·366194	[illegible]	43
18	10·018708	12·163236	15·463814	21·204949	33·693509	81·847041	42
19	10·048283	12·206716	15·533981	21·336851	34·027303	83·843507	41
20	10·078031	12·250505	15·604784	21·470401	34·367771	85·939791	40
21	10·107954	12·294609	15·676233	21·605630	[illegible]	88·143572	39
22	10·138054	[illegible]	15·748337	21·742569	35·069546	90·463336	38
23	10·168332	12·383768	[illegible]	[illegible]	[illegible]	92·908487	37
24	10·198789	12·428431	15·894545	22·021710	35·800553	95·489475	36
25	10·229428	12·474221	15·968667	22·163980	36·177596	98·217943	35
26	10·260249	[illegible]	[illegible]	[illegible]	36·562659	101·10690	34
27	10·291255	12·565997	[illegible]	[illegible]	36·956001	104·17094	33
28	10·322417	12·612390	16·195225	22·602015	37·357892	107·42648	32
29	10·353827	12·659125	16·272174	22·751892	37·768613	110·89205	31
30	10·385397	12·706205	16·349855	22·903766	38·188459	[illegible]	30
31	10·417158	12·753634	16·428279	23·057677	38·617738	118·54018	29
32	10·449112	12·801417	16·507456	[illegible]	39·056771	122·77396	28
33	10·481261	12·849557	16·587396	23·371777	39·505895	127·32134	27
34	10·513607	12·898058	16·668112	23·532052	39·965460	132·21851	26
35	10·546151	12·946924	16·749614	23·694537	40·435837	137·50745	25
36	10·578895	12·996160	16·831915	23·859277	40·917412	143·23712	24
37	10·611841	13·045769	16·915025	24·026320	41·410588	149·46502	23
38	10·644992	13·095757	16·998957	24·195714	41·915790	[illegible]	22
39	10·678348	13·146127	17·083724	24·367509	[illegible]	163·70019	21
40	10·711913	13·196883	17·169337	24·541758	42·964077	[illegible]	20
41	10·745687	13·248031	17·255809	24·718512	43·508122	180·93220	19
42	10·779673	13·299574	17·343155	24·897826	44·066113	[illegible]	18
43	10·813872	13·351518	17·431385	25·079757	44·638596	202·21875	17
44	10·848288	[illegible]	17·520516	25·264361	[illegible]	214·85762	16
45	10·882921	13·456625	17·610559	25·451700	45·829351	[illegible]	15
46	10·917775	13·509799	[illegible]	[illegible]	46·448862	245·55198	14
47	10·952850	13·563391	17·793442	25·834823	47·085343	264·44080	13
48	10·988150	13·617409	17·886310	26·030736	47·739501	286·47773	12
49	11·023676	13·671856	17·980150	26·229638	48·412084	312·52137	11
50	11·059431	13·726738	18·074977	26·431600	49·103881	343·77371	10
51	11·095416	13·782060	18·170807	26·636690	49·815726	381·97099	9
52	11·131635	13·837827	18·267654	26·844984	50·548506	429·71757	8
53	11·168089	13·894045	18·365537	27·056557	[illegible]	491·10600	7
54	11·204780	13·950719	18·464471	27·271486	52·080673	572·05721	6
55	11·241712	14·007856	18·564473	27·489853	52·882109	687·54887	5
56	11·278885	14·065459	18·665562	27·711740	53·708587	[illegible]	4
57	11·316304	14·123536	18·767754	27·937233	54·561300	1145·9153	3
58	11·353970	14·182092	18·871068	28·166422	55·441517	1718·8732	2
59	11·391885	14·241134	18·975523	28·399397	56·350590	3437·7467	1
60	11·430052	14·300666	19·081137	28·636253	57·289962	Infinite.	0
′	5°	4°	3°	2°	1°	0°	′

CO-TANGENTS.

SECANTS.

′	0°	1°	2°	3°	4°	5°	6°	′
0	1.0000000	1·0001523	1·0006095	1·0013723	1·0024419	1·0038198	1·0055083	60
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	58
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57
4	1·0000007	1·0001733	1·0006509	1·0014341	1·0025241	1·0039227	1·0056319	56
5	1·0000011	1·0001788	1·0006614	1·0014497	1·0025449	1·0039486	1·0056631	55
6	1·0000015	1·0001843	1·0006721	1·0014655	1·0025658	1·0039747	1·0056943	54
7	1·0000021	1·0001900	1·0006828	1·0014813	1·0025867	1·0040008	1·0057256	53
8	[illegible]	1·0001957	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52
9	1·0000034	1·0002015	1·0007045	1·0015132	1·0026289	1·0040533	1·0057885	51
10	1·0000042	1·0002073	1·0007154	1·0015293	1·0026501	1·0040796	1·0058200	50
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49
12	1·0000061	1·0002194	1·0007376	1·0015617	1·0026928	1·0041326	[illegible]	48
13	1·0000072	1·0002255	1·0007489	1·0015780	1·0027142	1·0041592	1·0059153	47
14	[illegible]	1·0002317	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46
15	1·0000095	1·0002380	1·0007716	1·0016109	1·0027574	1·0042127	1·0059792	45
16	1·0000108	1·0002444	1·0007830	1·0016275	1·0027791	1·0042396	1·0060113	44
17	1·0000122	1·0002509	1·0007946	1·0016442	1·0028009	1·0042666	1·0060435	43
18	1·0000137	1·0002575	1·0008063	1·0016609	1·0028228	1·0042937	1·0060757	42
19	1·0000153	1·0002641	1·0008180	1·0016778	1·0028448	1·0043208	1·0061081	41
20	1·0000169	1·0002708	1·0008298	1·0016947	1·0028669	1·0043480	1·0061405	40
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	1·0000224	1·0002915	1·0008658	1·0017460	1·0029336	1·0044302	[illegible]	37
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	1·0000264	1·0003058	1·0008902	1·0017806	1·0029785	1·0044855	1·0063040	35
26	1·0000286	1·0003130	1·0009025	1·0017981	1·0030010	1·0045132	1·0063370	34
27	1·0000308	1·0003203	1·0009149	1·0018156	1·0030237	1·0045411	1·0063701	33
28	1·0000332	1·0003277	1·0009274	1·0018332	1·0030464	1·0045690	1·0064032	32
29	1·0000356	1·0003352	1·0009400	1·0018509	1·0030693	1·0045970	1·0064364	31
30	1·0000381	1·0003428	1·0009527	1·0018687	1·0030922	1·0046251	1·0064697	30
31	1·0000407	1·0003505	1·0009654	1·0018866	1·0031152	1·0046533	1·0065031	29
32	1·0000433	1·0003582	1·0009783	1·0019045	1·0031383	1·0046815	1·0065366	28
33	1·0000461	1·0003660	1·0009912	1·0019225	1·0031615	1·0047099	1·0065702	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	1·0000518	1·0003820	1·0010173	1·0019589	1·0032081	1·0047669	1·0066379	25
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	1·0000579	1·0003982	1·0010438	1·0019956	1·0032551	1·0048242	1·0067054	23
38	1·0000611	1·0004065	1·0010571	1·0020140	1·0032787	1·0048530	1·0067394	22
39	1·0000644	1·0004148	1·0010705	1·0020326	1·0033024	1·0048819	1·0067735	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	1·0000782	1·0004490	1·0011251	1·0021076	1·0033980	1·0049982	[illegible]	17
44	1·0000819	1·0004578	1·0011390	1·0021266	1·0034221	1·0050275	1·0069453	16
45	1·0000857	1·0004666	1·0011529	1·0021457	1·0034463	1·0050569	1·0069799	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	1·0000935	1·0004846	1·0011811	1·0021841	1·0034950	1·0051160	1·0070404	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	1·0001016	1·0005029	1·0012096	1·0022228	1·0035440	1·0051754	1·0071103	11
50	1·0001058	1·0005121	1·0012239	1·0022423	1·0035687	1·0052052	1·0071544	10
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	1·0001231	1·0005501	1·0012823	1·0023211	1·0036681	1·0053254	1·0072955	6
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
56	1·0001327	1·0005696	1·0013120	1·0023610	1·0037183	1·0053860	1·0073666	4
57	1·0001375	1·0005794	1·0013269	1·0023811	1·0037436	1·0054164	1·0074023	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	1·0001473	1·0005994	1·0013571	1·0024216	1·0037943	1·0054776	1·0074739	1
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
′	89°	88°	87°	86°	85°	84°	83°	′

CO-SECANTS.

SECANTS.

′	7°	8°	9°	10°	11°	12°	13°	′
0	1·0075098	1·0098276	1·0124651	1·0154266	1·0187167	1·0223406	1·0263041	60
1	1·0075459	1·0098689	1·0125118	1·0154787	1·0187743	1·0224039	1·0263731	59
2	1·0075820	1·0099103	1·0125586	1·0155310	1·0188321	1·0224672	1·0264421	58
3	1·0076182	1·0099518	1·0126055	1·0155833	1·0188899	1·0225307	1·0265113	57
4	1·0076545	1·0099934	1·0126524	1·0156357	1·0189478	1·0225942	1·0265806	56
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55
6	1·0077273	1·0100769	1·0127466	1·0157408	1·0190640	1·0227216	1·0267194	54
7	1·0077639	1·0101187	1·0127939	1·0157934	1·0191222	1·0227854	1·0267889	53
8	1·0078005	1·0101607	1·0128412	1·0158462	1·0191805	1·0228493	1·0268586	52
9	1·0078372	1·0102027	1·0128886	1·0158991	1·0192389	1·0229133	1·0269283	51
10	1·0078741	1·0102449	1·0129361	1·0159520	1·0192973	1·0229774	1·0269982	50
11	1·0079110	1·0102871	1·0129837	1·0160050	1·0193559	1·0230416	1·0270681	49
12	1·0079480	1·0103294	1·0130314	1·0160582	1·0194146	1·0231059	1·0271381	48
13	1·0079851	1·0103718	1·0130791	1·0161114	1·0194734	1·0231703	1·0272082	47
14	1·0080222	1·0104143	1·0131270	1·0161647	1·0195322	1·0232348	1·0272785	46
15	[illegible]	[illegible]	1·0131750	[illegible]	[illegible]	[illegible]	1·0273488	45
16	[illegible]	[illegible]	1·0132230	[illegible]	[illegible]	[illegible]	[illegible]	44
17	1·0081343	1·0105422	1·0132711	1·0163252	1·0197003	1·0234288	1·0274897	43
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	1·0082094	1·0106280	1·0133677	1·0164327	1·0198279	1·0235587	1·0276310	41
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·0236237	1·0277018	40
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
31	1·0086676	1·0111501	1·0139545	1·0170851	1·0205470	1·0243456	1·0284871	29
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28
33	1·0087452	1·0112384	1·0140536	1·0171952	1·0206682	1·0244781	1·0286311	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	1·0090592	1·0115951	1·0144535	1·0176390	1·0211566	1·0250119	1·0292111	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	1·0093386	1·0119118	1·0148082	1·0180321	1·0215888	1·0254839	1·0297237	12
49	1·0093788	1·0119575	1·0148592	1·0180887	1·0216510	1·0255518	1·0297973	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	1·0094596	1·0120489	1·0149616	1·0182020	1·0217755	1·0256877	1·0299449	9
52	1·0095001	1·0120048	1·0150129	1·0182588	1·0218379	1·0257558	1·0300188	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	1·0095815	1·0121869	1·0151158	1·0183728	1·0219630	1·0258923	1·0301669	6
55	[illegible]	1·0122330	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4
57	1·0097041	1·0123256	1·0152708	1·0185443	1·0221514	1·0260978	1·0303898	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	[illegible]	1·0124185	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	1·0098276	[illegible]	[illegible]	[illegible]	[illegible]	1·0263041	[illegible]	0
′	82°	81°	80°	79°	78°	77°	76°	′

CO-SECANTS.

SECANTS.

′	14°	15°	16°	17°	18°	19°	20°	′
0	[illegible]	1·0352762	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59
2	1·0307633	1·0354378	1·0404732	1·0458780	1·0516612	1·0578328	1·0644033	58
3	1·0308383	1·0355187	1·0405602	1·0459712	1·0517608	1·0579390	1·0645163	57
4	1·0309134	1·0355998	1·0406473	1·0460646	1·0518606	1·0580453	1·0646294	56
5	1·0309886	1·0356809	1·0407346	1·0461581	1·0519605	1·0581517	1·0647425	55
6	1·0310639	1·0357621	1·0408219	1·0462516	1·0520604	1·0582583	1·0648558	54
7	1·0311393	1·0358435	1·0409094	1·0463453	1·0521605	1·0583649	1·0649693	53
8	1·0312147	1·0359249	1·0409969	1·0464391	1·0522607	1·0584717	1·0650828	52
9	1·0312903	1·0360065	1·0410845	1·0465330	1·0523610	1·0585786	1·0651964	51
10	1·0313660	1·0360881	1·0411723	1·0466270	1·0524614	1·0586855	1·0653102	50
11	1·0314418	1·0361699	1·0412601	1·0467211	1·0525619	1·0587926	1·0654240	49
12	1·0315177	1·0362517	1·0413481	1·0468153	1·0526625	1·0588999	[illegible]	48
13	1·0315936	1·0363337	1·0414362	1·0469096	1·0527633	1·0590072	1·0656521	47
14	1·0316697	1·0364157	1·0415243	1·0470040	1·0528641	1·0591146	1·0657663	46
15	1·0317459	1·0364979	1·0416126	1·0470986	1·0529651	1·0592221	1·0658807	45
16	1·0318222	1·0365801	1·0417009	1·0471932	1·0530661	1·0593208	1·0659951	44
17	1·0318985	1·0366625	1·0417894	1·0472879	1·0531673	1·0594376	1·0661097	43
18	1·0319750	1·0367449	1·0418780	1·0473828	1·0532686	1·0595454	[illegible]	42
19	1·0320516	1·0368275	1·0419667	1·0474777	1·0533699	1·0596534	1·0663391	41
20	1·0321282	1·0369101	1·0420554	1·0475728	1·0534714	1·0597615	1·0664540	40
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	1·0325130	1·0373249	1·0425009	1·0480496	1·0539805	1·0603037	1·0670302	35
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
27	1·0326076	1·0374915	1·0426708	1·0482411	1·0541849	1·0605214	1·0672015	33
28	1·0327451	1·0375750	1·0427604	1·0483370	1·0542873	1·0606304	1·0673774	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	1·0329003	1·0377422	1·0429489	1·0485291	1·0544923	1·0608487	[illegible]	30
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	1·0332901	1·0381621	1·0433995	1·0490113	1·0550068	1·0613065	1·0681914	25
36	1·0333683	1·0382463	1·0434900	1·0491080	1·0551101	1·0615064	1·0683081	24
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
46	1·0341563	1·0390047	1·0444001	1·0500815	1·0561485	1·0626115	1·0694820	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	1·0345540	1·0395226	1·0448590	1·0505722	1·0566718	1·0631684	1·0700733	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
58	1·0351150	1·0401261	1·0455060	1·0512637	1·0574090	1·0639527	1·0709060	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	1·0352762	1·0402994	1·0456918	1·0514622	1·0576207	1·0641778	1·0711450	0
′	75°	74°	73°	72°	71°	70°	69°	′

CO-SECANTS.

SECANTS.

′	21°	22°	23°	24°	25°	26°	27°	′
0	1·0711450	[illegible]	[illegible]	[illegible]	[illegible]	1·1126019	1·1223262	[illegible]
1	[illegible]	[illegible]	1·0864946	1·0947781	[illegible]	1·1127599	1·1224927	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1226592	[illegible]
3	[illegible]	[illegible]	1·0867634	1·0950622	[illegible]	1·1130761	1·1228259	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1229928	56
5	[illegible]	[illegible]	1·0870326	1·0953467	[illegible]	1·1133929	1·1231598	55
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1135516	[illegible]	54
7	[illegible]	[illegible]	1·0873024	1·0956318	[illegible]	[illegible]	1·1234932	53
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1138692	1·1236616	52
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1238292	51
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1141874	1·1239969	50
11	[illegible]	[illegible]	1·0878435	1·0962036	1·1050324	1·1143467	1·1241648	49
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1145062	[illegible]	48
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1146658	[illegible]	47
14	[illegible]	[illegible]	1·0882506	1·0966337	[illegible]	1·1148255	1·1246693	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1149854	1·1248377	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1250063	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1153056	1·1251750	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1253439	[illegible]
19	[illegible]	[illegible]	1·0889317	1·0973533	[illegible]	[illegible]	1·1255130	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1256821	[illegible]
21	[illegible]	[illegible]	1·0892050	1·0976420	[illegible]	[illegible]	1·1258514	[illegible]
22	[illegible]	[illegible]	1·0893418	1·0977866	[illegible]	[illegible]	1·1260209	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1261905	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1263603	[illegible]
25	1·0741720	[illegible]	[illegible]	[illegible]	1·1071616	[illegible]	[illegible]	[illegible]
26	1·0742945	[illegible]	[illegible]	[illegible]	[illegible]	1·116753[illegible]	[illegible]	[illegible]
27	[illegible]	1·0820015	[illegible]	[illegible]	[illegible]	1·116914[illegible]	1·1268705	[illegible]
28	[illegible]	1·0821316	[illegible]	[illegible]	1·1076214	[illegible]	[illegible]	[illegible]
29	[illegible]	1·0822618	1·0903032	1·0988023	[illegible]	[illegible]	1·1272113	[illegible]
30	[illegible]	1·0823922	[illegible]	[illegible]	[illegible]	1·1174004	1·1273819	[illegible]
31	[illegible]	[illegible]	1·0905791	1·0990936	1·1080823	[illegible]	1·1275527	[illegible]
32	[illegible]	1·0826533	1·0907172	1·0992395	[illegible]	1·1177[illegible]	[illegible]	[illegible]
33	[illegible]	1·0827840	1·0908554	1·0993855	1·1083903	[illegible]	[illegible]	[illegible]
34	[illegible]	[illegible]	[illegible]	[illegible]	1·1085445	[illegible]	[illegible]	[illegible]
35	[illegible]	1·0830458	1·0911323	1·0996779	1·1086989	[illegible]	[illegible]	[illegible]
36	[illegible]	1·0831769	[illegible]	[illegible]	1·1088535	1·1183753	[illegible]	[illegible]
37	[illegible]	[illegible]	1·0914097	1·0999709	[illegible]	[illegible]	[illegible]	[illegible]
38	[illegible]	[illegible]	1·0915485	1·1001175	[illegible]	[illegible]	[illegible]	[illegible]
39	[illegible]	[illegible]	1·0916876	[illegible]	1·1093176	1·1188547	[illegible]	[illegible]
40	[illegible]	[illegible]	1·0918267	1·1004113	1·1094726	[illegible]	[illegible]	[illegible]
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1191916	[illegible]	[illegible]
42	[illegible]	[illegible]	1·0921053	1·1007[illegible]	1·1097[illegible]	[illegible]	[illegible]	[illegible]
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	[illegible]	[illegible]	1·0923845	1·1010004	1·1100[illegible]	[illegible]	[illegible]	[illegible]
45	[illegible]	[illegible]	1·0925243	1·1011480	[illegible]	1·1198472	[illegible]	[illegible]
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	[illegible]	[illegible]	1·0928042	1·1014436	1·1105616	[illegible]	[illegible]	[illegible]
48	[illegible]	[illegible]	1·0929444	1·1015916	1·1107177	1·1203305	[illegible]	[illegible]
49	[illegible]	[illegible]	1·0930846	1·1017397	1·1108740	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	1·0932251	1·1018879	[illegible]	[illegible]	[illegible]	[illegible]
51	[illegible]	[illegible]	1·0933656	1·1020363	[illegible]	1·1208350	1·13[illegible]	[illegible]
52	[illegible]	[illegible]	1·0935063	1·1021849	1·1113436	[illegible]	[illegible]	[illegible]
53	[illegible]	[illegible]	[illegible]	[illegible]	1·1115004	1·1211643	[illegible]	[illegible]
54	[illegible]	[illegible]	[illegible]	[illegible]	1·1116573	1·121[illegible]	[illegible]	[illegible]
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1214963	[illegible]	[illegible]
56	[illegible]	[illegible]	1·0940702	1·1027803	1·1119716	1·1216620	1·1318706	[illegible]
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·1320152	[illegible]
58	[illegible]	[illegible]	1·0943530	1·1030789	[illegible]	1·1219928	1·1322200	[illegible]
59	[illegible]	[illegible]	1·0944946	1·1032283	[illegible]	[illegible]	1·1323950	[illegible]
60	[illegible]	[illegible]	1·0946363	1·1033779	1·1126019	1·1223262	[illegible]	[illegible]
′	68°	67°	66°	65°	64°	63°	62°	′

CO-SECANTS.

SECANTS.

′	28°	29°	30°	31°	32°	33°	34°	′
0	1·1325701	1·1433541	1·1547005	1.1666334	1·1791784	1·1923633	1·2062179	60
1	1·1327453	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59
2	1·1329207	1·1437231	1·1550887	1·1670416	1·1796074	1·1928142	1·2066917	58
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57
4	1·1332719	1·1440927	1·1554775	1·1674504	1·1800372	1·1932658	1·2071662	56
5	1·1334478	1·1442778	1·1556722	1·1676551	1·1802523	1·1934918	1·2074037	55
6	1·1336238	1·1444630	1·1558670	1·1678599	1·1804676	1·1937181	1·2076415	54
7	1·1337999	1·1446484	1·1560620	1·1680649	1·1806831	1·1939446	1·2078794	53
8	1·1339762	1·1448339	1·1562572	1·1682701	1·1808988	1·1941712	1·2081175	52
9	1·1341527	1·1450196	1·1564525	1·1684755	1·1811146	1·1943980	1·2083559	51
10	1·1343293	1·1452055	1·1566480	1·1686810	1·1813307	1·1946251	1·2085944	50
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49
12	1·1346829	1·1455776	1·1570394	1·1690926	1·1817633	1·1950796	1·2090720	48
13	1·1348600	1·1457639	1·1572354	1·1692986	1.1819798	1·1953072	1·2093112	47
14	1·1350372	1·1459504	1·1574315	1·1695048	1·1821966	1·1955350	1·2095505	46
15	1·1352146	1·1461371	1·1576278	1·1697112	1·1824135	1·1957629	1·2097900	45
16	1·1353921	1·1463238	1·1578243	1·1699178	1·1826306	1·1959911	1·2100297	44
17	1·1355697	1·1465108	1·1580209	1·1701245	1·1828479	1·1962194	1·2102690	43
18	1·1357476	1·1466979	1·1582177	1·1703314	1·1830654	1·1964479	1·2105097	42
19	1·1359255	1·1468852	1·1584146	1·1705385	1·1832830	1·1966767	1·2107500	41
20	1·1361036	1·1470726	1·1586118	1·1707457	1·1835008	1·1969056	1·2109905	40
21	1·1362819	1·1472602	1·1588091	1·1709531	1·1837188	1·1971346	1·2112312	39
22	1·1364603	1·1474479	1·1590065	1·1711607	1·1839370	1·1973639	1·2114721	38
23	1·1366389	1·1476358	1·1592041	1·1713685	1·1841554	1·1975934	1·2117132	37
24	1·1368176	1·1478239	1·1594019	1·1715764	1·1843739	1·1978230	1·2119545	36
25	1·1369965	1·1480121	1·1595999	1·1717845	1·1845927	1·1980529	[illegible]	35
26	1·1371755	1·1482005	1·1597980	1·1719928	1·1848116	1·1982829	1·2124377	34
27	1·1373547	1·1483890	1·1599963	1·1722013	1·1850307	1·1985131	1·2126795	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	1·1377135	1·1487665	1·1603933	1·1726187	1·1854694	1·1989741	1·2131630	31
30	1·1378932	1·1489555	1·1605921	1·1728277	1·1856890	1·1992049	1·2134064	30
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29
32	1·1382529	1·1493340	1·1609902	1·1732462	1·1861289	1·1996671	1·2138920	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	1·1387937	1·1499030	1·1615885	1·1738752	1·1867900	1·2003618	1·2146218	25
36	1·1389742	1·1500930	1·1617883	1·1740852	1·1870107	1·2005937	1·2148655	24
37	1·1391550	1·1502831	1·1619882	1·1742954	1·1872316	1·2008258	1·2151094	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	1·1395169	1·1506638	1·1623886	1·1747163	1·1876740	1·2012907	1·2155978	21
40	1·1396980	1·1508544	1·1625891	1·1749270	1·1878954	1·2015234	1·2158423	20
41	1·1398794	1·1510452	1·1627897	1·1751379	1·1881171	1·2017563	1·2160870	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	1·1402425	1·1514272	1·1631914	1·1755603	1·1885609	1·2022226	1·2165770	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	1·1409706	1·1521932	1·1639968	1·1764070	1·1894508	1·2031577	1·2175594	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	1·1413356	1·1525772	1·1644007	1·1768314	1·1898968	1·2036264	1·2180518	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	1·1420674	1·1533470	1·1652102	1·1776824	1·1907911	1·2045660	1·2190390	7
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
56	1·1426179	1·1539261	1·1658191	1·1783225	1·1914638	1·2052728	1·2197816	4
57	1·1428017	1·1541195	1·1660224	1·1785362	1·1916884	1·2055088	1·2200296	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
′	61°	60°	59°	58°	57°	56°	55°	′

CO-SECANTS.

SECANTS.

′	35°	36°	37°	38°	39°	40°	41°	′
0	1·2207746	1·2360680	1·2521357	[illegible]	1·2867596	1·3054073	1·3250130	60
1	1·2210233	1·2363293	1·2524102	1·2693067	1·2870628	1·3057261	1·3253482	59
2	1·2212723	1·2365909	1·2526850	1·2695955	1·2873663	1·3060451	1·3256837	58
3	1·2215215	1·2368526	1·2529601	1·2698845	1·2876700	1·3063644	1·3260194	57
4	1·2217708	[illegible]	1·2532353	1·2701737	1·2879740	1·3066839	1·3263554	56
5	1·2220204	1·2373768	1·2535108	1.2704632	1·2882782	1·3070038	1·3266918	55
6	1·2222702	1·2376393	1·2537865	1·2707529	1·2885827	1·3073239	1·3270284	54
7	1·2225202	1·2379019	1·2540625	1·2710429	1·2888875	1·3076442	1·3273653	53
8	1·2227703	1·2381647	1·2543387	1·2713331	1·2891925	1·3079649	1·3277024	52
9	1·2230207	1·2384278	1·2546151	1·2716235	[illegible]	[illegible]	1·3280399	51
10	1·2232713	1·2386911	1·2548917	1·2719142	1·2898032	1·3086069	1·3283776	50
11	[illegible]	1·2389546	1·2551685	1·2722052	1·2901090	[illegible]	1·3287156	49
12	1·2237732	1·2392183	1·2554456	1·2724963	1·2904150	1·3092501	1·3290539	48
13	1·2240243	[illegible]	1·2557229	1·2727877	1·2907213	1·3095720	1·3293925	47
14	[illegible]	1·2397464	1·2560005	1·2730794	1·2910278	1·3098943	1·3297314	46
15	1·2245274	1·2400108	1·2562782	1·2733712	1·2913346	1·3102168	1·3300706	45
16	1·2247793	1·2402754	1·2565562	1·2736634	1·2916416	[illegible]	1·3304100	44
17	1·2250313	1·2405402	1·2568345	1·2739557	[illegible]	1·3108626	1·3307497	43
18	1·2252836	1·2408052	1·2571129	1·2742484	1·2922564	1·3111860	1·3310897	42
19	1·2255361	1·2410704	1·2573916	1·2745412	1·2925642	[illegible]	1·3314301	41
20	1·2257887	1·2413359	1·2576705	1·2748343	1·2928723	1·3118334	1·3317707	40
21	[illegible]	1·2416016	1·2579497	1·2751276	1·2931806	1·3121575	1·3321115	39
22	[illegible]	1·2418675	1·2582291	1·2754212	1·2934892	1·3124820	1·3324527	38
23	[illegible]	1·2421336	1·2585087	1·2757151	1·2937980	1·3128066	1·3327942	37
24	[illegible]	[illegible]	1·2587885	1·2760091	1·2941071	1·3131316	1·3331359	36
25	1·2270552	1·2426665	1·2590686	1·2763034	[illegible]	1·3134568	1·3334779	35
26	1·2273091	1·2429333	1·2593489	1·2765980	1·2947260	1·3137823	1·3338203	34
27	[illegible]	1·2432003	1·2596294	1·2768928	1·2950359	1·3141081	1·3341629	33
28	1·2278176	1·2434675	1·2599102	1·2771878	1·2953460	1·3144341	1·3345058	32
29	1·2280722	[illegible]	1·2601912	1·2774831	1·2956564	1·3147604	1·3348489	31
30	1·2283269	1·2440026	1·2604724	1·2777787	[illegible]	1·3150870	1·3351924	30
31	1·2285819	1·2442704	1·2607539	1·2780744	1·2962779	1·3154139	[illegible]	29
32	1·2288371	1·2445385	1·2610356	1·2783705	1·2965890	1·3157410	1·3358802	28
33	1·2290924	1·2448069	1·2613175	1·2786667	1·2969004	1·3160684	1·3362246	27
34	1·2293480	1·2450754	1·2615997	1·2789632	1·2972121	1·3163961	1·3365692	26
35	1·2296039	1·2453442	1·2618820	1·2792600	1·2975240	1·3167240	1·3369141	25
36	1·2298599	1·2456131	1·2621647	1·2795570	1·2978362	1·3170523	[illegible]	24
37	[illegible]	1·2458823	1·2624475	1·2798543	1·2981487	[illegible]	[illegible]	23
38	1·2303725	1·2461518	1·2627306	1·2801518	1·2984614	[illegible]	1·3379507	22
39	1·2306292	1·2464214	1·2630140	1·2804495	1·2987743	1·3180386	[illegible]	21
40	1·2308861	1·2466913	[illegible]	1·2807475	1·2990876	1·3183680	1·3386432	20
41	1·2311432	1·2469614	1·2635813	1·2810457	1·2994011	1·3186976	1·3389898	19
42	1·2314004	1·2472317	1·2638653	1·2813442	1·2997148	1·3190274	1·3393368	18
43	1·2316579	1·2475022	1·2641496	1·2816430	1·3000288	1·3193576	[illegible]	17
44	1·2319156	1·2477730	1·2644341	[illegible]	1·3003431	1·3196881	1·3400316	16
45	1·2321736	1·2480440	1·2647188	[illegible]	1·3006576	1·3200188	[illegible]	15
46	1·2324317	1·2483152	1·2650038	1·2825407	[illegible]	1·3203498	1·3407276	14
47	[illegible]	1·2485866	1·2652890	[illegible]	1·3012875	1·3206810	1·3410761	13
48	[illegible]	1·2488583	1·2655745	1·2831401	1·3016028	1·3210126	1·3414248	12
49	1·2332074	1·2491302	1·2658601	1·2834406	1·3019184	1·3213444	1·3417738	11
50	1·2334664	1·2494023	1·2661460	1·2837411	1·3022343	1·3216765	1·3421232	10
51	1·2337256	1·2496746	1·2664322	[illegible]	[illegible]	1·3220089	1·3424728	9
52	1·2339850	1·2499471	1·2667186	1·2843428	1·3028667	1·3223416	1·3428227	8
53	1·2342446	1·2502199	1·2670052	1·2846440	1·3031834	1·3226745	1·3431729	7
54	1·2345044	1·2504929	1·2672921	1·2849455	1·3035003	1·3230078	1·3435234	6
55	1·2347645	1·2507661	1·2675792	1·2852472	1·3038175	1·3233413	1·3438742	5
56	1·2350248	1·2510396	1·2678665	1·2855492	1·3041349	1·3236750	[illegible]	4
57	1·2352852	1·2513133	1·2681541	1·2858514	1·3044526	1·3240091	1·3445767	3
58	1·2355459	1·2515872	1·2684419	1·2861539	[illegible]	1·3243435	[illegible]	2
59	1·2358069	1·2518613	1·2687299	1·2864566	1·3050888	1·3246781	1·3452804	1
60	1·2360680	1·2521357	1·2690182	1·2867596	1·3054073	1·3250130	1·3456327	0
′	54°	53°	52°	51°	50°	49°	48°	′

CO-SECANTS.

SECANTS.

′	42°	43°	44°	45°	46°	47°	48°	′
0	1·3456327	1·3673275	1·3901636	1·4142136	1·4395565	1·4662792	1·4944765	60
1	1·3459853	1·3676985	1·3905543	1·4146251	1·4399904	1·4667368	1·4949596	59
2	1·3463382	1·3680699	1·3909453	1·4150370	1·4404246	1·4671948	1·4954431	58
3	1·3466914	1·3684416	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57
4	1·3470449	1·3688136	1·3917283	1·4158619	1·4412941	1·4681120	1·4964113	56
5	1·3473987	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55
6	1·3477528	1·3695586	1·3925127	1·4166883	1·4421652	1·4690309	1·4973813	54
7	1·3481072	1·3699315	1·3929054	1·4171020	1·4426013	1·4694910	1·4978670	53
8	1·3484619	1·3703048	[illegible]	1·4175161	[illegible]	[illegible]	[illegible]	52
9	1·3488168	1·3706784	1·3936918	1·4179306	1·4434748	1·4704123	1·4988397	51
10	1·3491721	1·3710523	1·3940856	1·4183454	[illegible]	[illegible]	[illegible]	50
11	1·3495277	1·3714266	1·3944796	1·4187605	1·4443497	1·4713354	1·4998141	49
12	1·3498836	1·3718011	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48
13	1·3502398	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47
14	1·3505963	1·3725512	1·3956639	1·4200082	1·4456651	1·4727230	1·5012791	46
15	1·3509531	1·3729268	[illegible]	1·4204248	[illegible]	[illegible]	[illegible]	45
16	1·3513102	1·3733026	1·3964551	1·4208418	1·4465439	1·4736502	1·5022580	44
17	1·3516677	1·3736788	1·3968512	1·4212592	1·4469839	1·4741144	1·5027481	43
18	1·3520254	1·3740553	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	1·3523834	1·3744321	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41
20	1·3527417	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
21	1·3531003	1·3751867	1·3984391	1·4229323	1·4487478	1·4759754	1·5047131	39
22	1·3534593	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	1·3538185	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37
24	1·3541780	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	1·3545379	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25
36	1·3585164	1.3808877	1·4044430	1·4292588	1·4554187	1·4830142	[illegible]	24
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	1·3640022	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	[illegible]	1·3882153	[illegible]	[illegible]	[illegible]	[illegible]	1·5212012	5
56	[illegible]	1·3886043	[illegible]	[illegible]	[illegible]	[illegible]	1·5222166	4
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·5227250	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·5237433	1
60	[illegible]	[illegible]	1·4142136	[illegible]	[illegible]	1·4944765	1·5242531	0
′	47°	46°	45°	44°	43°	42°	41°	′

CO-SECANTS.

SECANTS.

′	49°	50°	51°	52°	53°	54°	55°	′
0	1·5242531	1·5557238	1·5890157	1·6242692	1·6616401	1·7013016	1·7434468	60
1	1·5247634	1·5562634	1·5895868	1·6248743	1·6622819	1·7019831	1·7441715	59
2	1·5252741	1·5568035	1·5901584	[illegible]	1·6629243	1·7026653	1·7448969	58
3	1·5257854	[illegible]	1·5907306	1·6260861	1·6635673	1·7033482	1·7456230	57
4	[illegible]	[illegible]	1·5913033	1·6266929	1·6642110	1·7040318	[illegible]	56
5	1·5268093	1·5584268	1·5918766	1·6273003	1·6648553	1·7047160	[illegible]	55
6	1·5273219	1·5589689	1·5924504	[illegible]	[illegible]	1·7054010	1·7478060	54
7	[illegible]	[illegible]	[illegible]	1·6285169	1·6661458	1·7060867	1·7485352	53
8	1·5283487	1·5600546	[illegible]	1·6291261	1·6667920	1·7067730	1·7492651	52
9	1·5288627	1·5605982	[illegible]	1·6297359	1·6674389	1·7074601	1·7499958	51
10	1·5293773	1·5611424	1·5947511	1·6303462	1·6680864	1·7081478	1·7507273	50
11	1·5298923	1·5616871	1·5953276	[illegible]	[illegible]	1·7088362	1·7514595	49
12	1·5304078	1·5622322	1·5959048	1·6315688	1·6693833	[illegible]	1·7521924	48
13	1·5309238	[illegible]	[illegible]	1·6321809	1·6700328	1·7102152	1·7529262	47
14	1·5314403	1·5633241	1·5970606	1·6327937	1·6706828	1·7109058	1·7536607	46
15	1·5319572	1·5638708	1·5976394	1·6334070	1·6713336	1·7115970	1·7543959	45
16	1·5324746	[illegible]	1·5982187	[illegible]	[illegible]	1·7122890	1·7551320	44
17	[illegible]	1·5649658	1·5987986	[illegible]	[illegible]	1·7129817	1·7558687	43
18	[illegible]	1·5655141	1·5993790	1·6352507	1·6732897	1·7136750	1·7566063	42
19	[illegible]	[illegible]	1·5999600	1·6358664	1·6739430	[illegible]	[illegible]	41
20	[illegible]	1·5666121	1·6005416	1·6364828	1·6745970	1·7150639	1·7580837	40
21	1·5350689	1·5671619	1·6011237	1·6370997	1·6752517	1·7157594	1·7588236	39
22	1·5355892	1·5677123	[illegible]	1·6377173	1·6759070	1·7164556	1·7595642	38
23	1·5361100	[illegible]	[illegible]	1·6383355	1·6765629	1·7171525	1·7603057	37
24	[illegible]	1·5688145	1·6028734	1·6389542	1·6772195	1·7178501	1·7610478	36
25	1·5371550	1·5693664	1·6034577	[illegible]	[illegible]	1·7185484	1·7617908	35
26	1·5376752	1·5699188	1·6040426	1·6401936	1·6785347	1·7192475	1·7625345	34
27	[illegible]	1·5704717	1·6046281	[illegible]	[illegible]	1·7199472	1·7632791	33
28	1·5387212	1·5710252	1·6052142	[illegible]	[illegible]	1·7206477	1·7640244	32
29	1·5392449	1·5715792	1·6058008	1·6420572	1·6805124	1·7213489	1·7647704	31
30	[illegible]	1·5721337	1·6063879	1·6426796	1·6811730	1·7220508	1·7655173	30
31	1·5402937	[illegible]	1·6069757	1·6433027	1·6818342	[illegible]	1·7662649	29
32	1·5408189	[illegible]	1·6075640	1·6439263	[illegible]	[illegible]	1·7670133	28
33	1·5413445	1·5738004	1·6081528	1·6445506	1·6831586	1·7241609	1·7677625	27
34	1·5418706	[illegible]	1·6087423	[illegible]	[illegible]	1·7248657	1·7685125	26
35	1·5423973	1·5749141	[illegible]	1·6458009	[illegible]	1·7255712	1·7692633	25
36	[illegible]	[illegible]	1·6099228	1·6464270	1·6851503	1·7262774	1·7700149	24
37	1·5434520	[illegible]	1·6105140	1·6470537	1·6858155	1·7269844	1·7707672	23
38	1·5439801	1·5765887	[illegible]	1·6476811	1·6864814	1·7276921	1·7715204	22
39	1·5445087	1·5771479	1·6116980	1·6483090	1·6871479	1·7284005	1·7722743	21
40	1·5450378	1·5777077	1·6122908	1·6489376	1·6878151	1·7291096	1·7730290	20
41	[illegible]	1·5782680	[illegible]	1·6495668	1·6884830	1·7298105	1·7737845	19
42	[illegible]	1·5788289	[illegible]	1·6501966	1·6891516	1·7305301	1·7745409	18
43	1·5466280	[illegible]	1·6140728	1·6508270	1·6898202	1·7312414	1·7752980	17
44	[illegible]	[illegible]	1·6146680	1·6514581	1·6904907	1·7319535	[illegible]	16
45	1·5476906	1·5805146	1·6152637	1·6520898	1·6911613	1·7326663	1·7768146	15
46	1·5482226	1·5810776	[illegible]	1·6527221	1·6918326	1·7333798	[illegible]	14
47	1·5487552	[illegible]	1·6164569	1·6533550	1·6925045	1·7340941	1·7783344	13
48	1·5492882	[illegible]	1·6170544	[illegible]	[illegible]	1·7348091	[illegible]	12
49	1·5498218	1·5827697	1·6176524	1·6546227	1·6938504	1·7355248	1·7798574	11
50	1·5503558	1·5833348	1·6182510	[illegible]	[illegible]	1·7362413	1·7806201	10
51	1·5508904	1·5839005	1·6188502	1·6558929	1·6951990	1·7369585	1·7813836	9
52	1·5514254	1·5844667	1·6194500	1·6565290	1·6958744	1·7376764	[illegible]	8
53	1·5519610	1·5850334	1·6200504	1·6571657	1·6965504	1·7383951	1·7829131	7
54	1·5524970	1·5856007	1·6206513	1·6578030	1·6972271	1·7391145	1·7836790	6
55	1·5530335	1·5861685	1·6212528	1·6584409	1·6979044	1·7398347	1·7844457	5
56	1·5535706	1·5867369	1·6218549	1·6590795	1·6985825	1·7405556	1·7852133	4
57	1·5541081	1·5873058	1·6224576	1·6597187	1·6992612	1·7412773	1·7859817	3
58	1·5546462	1·5878752	1·6230609	1·6603586	1·6999407	1·7419997	[illegible]	2
59	1·5551848	1·5884452	1·6236648	1·6609990	1·7006208	1·7427229	1·7875208	1
60	1·5557238	1·5890157	1·6242692	1·6616401	1·7013016	1·7434468	1·7882916	0
′	40°	39°	38°	37°	36°	35°	34°	′

CO-SECANTS.

SECANTS

′	56°	57°	58°	59°	60°	61°	62°	′
0	1·7882916	1·8360785	1·8870799	1·9416040	2·0000000	[illegible]	[illegible]	60
1	[illegible]	1·8369013	1·8879589	1·9425445	2·0010083	2·0637484	2·1312205	59
2	[illegible]	1·8377251	1·8888388	1·9434861	2·0020177	2·0648328	2·1323880	58
3	[illegible]	1·8385498	1·8897197	1·9444288	2·0030283	2·0659186	2·1335570	57
4	1·7913831	1·8393753	1·8906016	1·9453725	2·0040402	2·0670056	2·1347274	56
5	1·7921580	1·8402015	1·8914845	1·9463173	[illegible]	[illegible]	[illegible]	55
6	1·7929337	1·8410292	1·8923684	1·9472632	[illegible]	[illegible]	[illegible]	54
7	1·7937102	1·8418574	1·8932532	1·9482102	2·0070828	2·0702746	2·1382475	53
8	1·7944876	1·8426866	1·8941391	1·9491583	2·0080994	2·0713670	2·1394238	52
9	1·7952658	1·8435166	1·8950259	1·9501075	2·0091172	2·0724606	2·1406015	51
10	1·7960449	1·8443476	[illegible]	[illegible]	2·0101362	[illegible]	[illegible]	50
11	1·7968247	1·8451795	1·8968026	1·9520091	2·0111564	2·0746519	2·1429615	49
12	1·7976054	1·8460123	1·8976924	1·9529615	2·0121779	2·0757496	2·1441438	48
13	1·7983869	1·8468460	1·8985832	1·9539150	2·0132005	2·0768486	2·1453275	47
14	1·7991693	1·8476806	1·8994750	1·9548697	2·0142243	2·0779489	2·1465127	46
15	[illegible]	1·8485101	1·9003678	[illegible]	[illegible]	[illegible]	[illegible]	45
16	1·8007365	1·8493525	1·9012616	1·9567822	2·0162756	2·0801536	[illegible]	44
17	1·8015213	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43
18	1·8023070	1·8510281	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	1·8030935	1·8518672	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41
20	1·8038809	1·8527073	1·9048469	1·9606206	2·0203929	2·0845792	[illegible]	40
21	1·8046691	1·8535483	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	1·8054582	1·8543903	1·9066450	[illegible]	[illegible]	[illegible]	[illegible]	38
23	1·8062481	1·8552331	1·9075464	1·9635110	2·0234937	2·0879127	2·1572469	37
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	[illegible]	[illegible]	1·9093512	[illegible]	[illegible]	[illegible]	[illegible]	35
26	1·8086228	1·8577672	1·9102551	1·9664114	2·0266056	2·0912584	2·1608522	34
27	1·8094161	1·8586138	1·9111600	1·9673805	2·0276453	2·0923764	2·1620570	33
28	1·8102102	1·8594612	1·9120659	1·9683507	2·0286863	2·0934957	2·1632633	32
29	1·8110052	1·8603097	1·9129729	1·9693220	2·0297286	2·0946164	2·1644712	31
30	1·8118010	1·8611590	1·9138809	1·9702944	2·0307720	2·0957385	2·1656806	30
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	1·9175240	[illegible]	[illegible]	[illegible]	[illegible]	26
35	1·8157930	1·8654197	1·9184362	1·9751735	2·0360082	2·1013698	[illegible]	25
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	1·8206118	1·8705637	1·9239366	1·9810659	2·0423330	2·1081733	2·1790859	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	1·8238416	1·8740120	1·9276244	1·9850172	2·0465750	2·1127371	2·1840074	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2·1138815	[illegible]	14
47	1·8254017	1·8757419	1·9294746	1·9869907	2·0487036	2·1150274	[illegible]	13
48	1·8262731	1·8766082	1·9304013	1·9879927	2·0497698	2·1161748	[illegible]	12
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	1·8287125	1·8792131	1·9331876	1·9909787	2·0529762	2·1196253	2·1914370	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	1·8311599	1·8818266	1·9350835	1·9939753	2·0561942	2·1230887	[illegible]	6
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4
57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
60	[illegible]	[illegible]	[illegible]	2·0000000	[illegible]	[illegible]	[illegible]	0
′	33°	32°	31°	30°	29°	28°	27°	′

CO-SECANTS.

SECANTS.

′	63°	64°	65°	66°	67°	68°	69°	′
0	2·2026893	2·2811720	2·3662016	2·4585933	2·5593047	2·6694672	2·7904281	60
1	2·2039476	2·2825335	2·3676787	2·4602008	2·5610599	2·6713906	2·7925444	59
2	2·2052075	2·2838967	2·3691578	2·4618106	2·5628176	2·6733171	2·7946641	58
3	2·2064691	2·2852618	2·3706390	2·4634227	2·5645781	2·6752465	2·7967873	57
4	2·2077323	2·2866286	2·3721222	2·4650371	2·5663412	2·6771790	2·7989140	56
5	2·2089972	2·2879974	2.3736075	2·4666538	2·5681069	2·6791145	[illegible]	55
6	2·2102637	2·2893679	2·3750049	2·4682729	2·5698752	2·6810530	2·8031777	54
7	2·2115318	2·2907403	2·3765843	2·4698943	2·5716462	2·6829945	2·8053148	53
8	2·2128016	2·2921145	2·3780758	2·4715181	2·5734199	[illegible]	2·8074554	52
9	2·2140730	2·2934906	2·3795694	2·4731442	2·5751963	[illegible]	2·8095905	51
10	2·2153460	2·2948685	2·3810650	2·4747726	2·5769753	[illegible]	2·8117471	50
11	2·2166208	2·2962483	2·3825627	2·4764034	2·5787570	[illegible]	[illegible]	49
12	2·2178971	2·2976299	2·3840625	2·4780366	2·5805414	[illegible]	2·8160529	48
13	2·2191752	[illegible]	2·3855645	2·4796721	2·5823284	[illegible]	[illegible]	47
14	2·2204548	[illegible]	2·3870685	2·4813100	2·5841182	[illegible]	2·8203729	46
15	2·2217362	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2·8225382	45
16	2·2230192	2·3031751	2·3900828	2·4845929	2·5877058	2·7006061	2·8247071	44
17	2·2243039	[illegible]	2·3915931	2·4862380	2·5895037	2·7025784	2·8268796	43
18	2·2255903	2·3059588	2·3931055	2·4878854	2·5913043	2·7045538	2·8290556	42
19	[illegible]	2·3073536	2·3946201	2·4895352	2·5931077	2·7065323	2·8312353	41
20	2·2281681	2·3087501	2·3961367	2·4911874	2·5949137	2·7085139	2·8334185	40
21	[illegible]	2·3101486	[illegible]	[illegible]	2·5967225	2·7104987	2·8356054	39
22	2·2307526	2·3115490	2·3991764	2·4944991	2·5985341	2·7124866	2·8377958	38
23	2·2320473	[illegible]	2·4006995	2·4961586	2·6003484	2·7144777	2·8399899	37
24	2·2333435	2·3143554	2·4022247	2·4978204	2·6021654	2·7164719	[illegible]	36
25	2·2346420	2·3157615	[illegible]	[illegible]	[illegible]	2·7184693	[illegible]	35
26	2·2359419	2·3171695	2·4052815	2·5011515	2·6058078	2·7204698	2·8465911	34
27	2·2372435	2·3185794	2·4068132	2·5028207	2·6076332	[illegible]	2·8488028	33
28	[illegible]	2·3199912	2·4083469	2·5044923	2·6094613	2·7244804	[illegible]	32
29	2·2398517	2·3214049	2·4098829	2·5061663	2·6112922	[illegible]	2·8532312	31
30	2·2411585	[illegible]	2·4114210	2·5078428	2·6131259	2·7285038	2·8554510	30
31	2·2424669	[illegible]	2·4129613	2·5095218	2·6149624	2·7305203	2·8576744	29
32	2·2437770	[illegible]	2·4145038	2·5112032	2·6168018	2·7325400	2·8599015	28
33	[illegible]	2·3270790	2·4160484	2·5128871	2·6186439	2·7345630	[illegible]	27
34	2·2464025	2·3285023	2·4175952	2·5145735	2·6204888	2·7365892	2·8643670	26
35	2·2477178	2·3299276	2·4191442	2·5162624	2·6223366	2·7386186	2·8666053	25
36	2·2490348	2·3313548	2·4206954	2·5179537	2·6241872	2·7406512	2·8688474	24
37	2·2503536	[illegible]	2·4222488	2·5196475	2·6260406	2·7426871	2·8710932	23
38	2·2516741	2·3342152	[illegible]	[illegible]	[illegible]	2·7447263	[illegible]	22
39	2·2529964	[illegible]	2·4253622	2·5230426	2·6297560	2·7467687	[illegible]	21
40	2·2543204	2·3370833	[illegible]	[illegible]	[illegible]	2·7488144	[illegible]	20
41	2·2556461	[illegible]	[illegible]	[illegible]	[illegible]	2·7508634	2·8801142	19
42	2·2569736	2·3399593	[illegible]	[illegible]	[illegible]	2·7529157	2·8823789	18
43	2·2583029	2·3414002	2·4316155	2·5298630	2·6372211	2·7549712	2·8846474	17
44	2·2596339	2·3428432	2·4331844	2·5315744	2·6390946	2·7570301	[illegible]	16
45	2·2609667	2·3442881	2·4347555	2·5332883	2·6409710	2·7590923	2·8891960	15
46	2·2623012	2·3457349	2·4363289	2·5350048	2·6428502	2·7611578	2·8914760	14
47	2·2636376	2·3471838	[illegible]	[illegible]	[illegible]	[illegible]	2·8937598	13
48	2·2649756	[illegible]	2·4391823	2·5384453	2·6466174	2·7652988	2·8960475	12
49	2·2663155	[illegible]	2·4410624	2·5401694	2·6485054	2·7673744	2·8983391	11
50	2·2676571	2·3515424	[illegible]	[illegible]	[illegible]	2·7694532	2·9006346	10
51	2·2690005	2·3529992	2·4442294	2·5436253	2·6522901	2·7715355	2·9029339	9
52	2·2703457	2·3544581	[illegible]	2·5453571	[illegible]	2·7736211	2·9052372	8
53	2·2716927	2·3559189	2·4474054	2·5470915	2·6560865	2·7757100	2·9075443	7
54	2·2730415	2·3573818	2 4489968	2·5488284	2·6579891	2·7778024	2·9098553	6
55	2·2743921	[illegible]	2·4505905	2·5505680	2·6598947	2·7798982	2·9121703	5
56	2·2757445	2·3603136	2·4521865	2·5523101	2·6618033	2·7819973	2·9144892	4
57	[illegible]	2·3617826	2·4537848	2·5540548	2·6637148	[illegible]	2·9168121	3
58	2·2784546	2·3632535	2·4553853	2·5558022	2·6656292	2·7862059	2·9191389	2
59	2·2798124	2·3647265	2·4569882	2·5575521	2·6675467	2·7883153	2·9214697	1
60	2·2811720	2·3662016	2·4585933	2·5593047	2·6694672	2·7904281	2·9238044	0
′	26°	25°	24°	23°	22°	21°	20°	′

CO-SECANTS.

SECANTS.

′	70°	71°	72°	73°	74°	75°	76°	′
0	2·9238044	3·0715535	3·2360680	3·4203036	3·6279553	3·8637033	[illegible]	60
1	[illegible]	3·0741507	[illegible]	3·4235011	[illegible]	[illegible]	[illegible]	59
2	2·9284858	3·0767525	3·2418732	[illegible]	3·6353316	[illegible]	[illegible]	58
3	2·9308326	3·0793590	3·2447840	[illegible]	[illegible]	[illegible]	[illegible]	57
4	2·9331833	3·0819702	3·2477003	[illegible]	[illegible]	[illegible]	[illegible]	56
5	2·9355380	3·0845860	3·2500222	[illegible]	[illegible]	[illegible]	[illegible]	55
6	2·9378968	3·0872066	3·2535490	[illegible]	[illegible]	[illegible]	[illegible]	54
7	2·9402597	3·0898319	3·2564825	3·4432433	3·6539097	3·8932976	4·1676102	53
8	2·9426265	3·0924620	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51
10	2·9473725	3·0977363	3·2653149	3·4531735	3·6651518	3·9061250	4·1823785	50
11	2·9497516	3·1003805	3·2682702	[illegible]	[illegible]	[illegible]	[illegible]	49
12	2·9521348	3·1030296	3·2712311	[illegible]	[illegible]	[illegible]	[illegible]	48
13	2·9545221	3·1056835	3·2741977	3·4631637	3·6764660	3·9190403	4·1972549	47
14	[illegible]	3·1083422	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46
15	[illegible]	3·1110057	3·2801479	[illegible]	[illegible]	[illegible]	[illegible]	45
16	[illegible]	3·1136740	3·2831310	3·4732140	[illegible]	[illegible]	4·2122408	44
17	2·9641125	3·1163472	3·2861209	3·4765785	3·6916652	[illegible]	[illegible]	43
18	2·9665205	3·1190252	3·2891160	3·4799492	3·6954854	3·9407633	[illegible]	42
19	2·9689327	3·1217081	3·2921168	3·4833267	3·6993139	3·9451379	4·2273373	41
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
21	[illegible]	[illegible]	[illegible]	3·4901023	[illegible]	[illegible]	[illegible]	39
22	2·9761942	3·1297862	3·3011539	3·4935004	3·7108489	3·9583219	[illegible]	3
23	2·9786231	3·1324887	3·3041778	3·4969055	3·7147105	3·9627369	[illegible]	3
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	2·9834936	3·1379086	3·3102432	3·5037305	3·7224589	3·9715975	4·2578071	35
26	2·9859352	3·1406259	[illegible]	3·5071025	[illegible]	[illegible]	[illegible]	34
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
30	2·9957443	3·1515453	3·3255095	3·5209305	3·7419775	3·9939292	4·2830570	30
31	2·9982073	3·1542877	3·3285805	3·5243977	3·7459068	3·9984267	4·2888543	29
32	3·0006746	3·1570351	3·3316575	3·5278000	3·7498447	4·0029347	[illegible]	28
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26
35	3·0081024	3·1653078	3·3409244	3·5383138	3·7617100	4·0165219	4·3097715	25
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
37	3·0130760	3·1708484	3·3471324	3·5453149	3·7696636	4·0256332	4·3203090	23
38	3·0155694	3·1736264	3·3502455	3·5488203	3·7736535	4·0302048	4·3255977	22
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
51	[illegible]	3·2162132	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
55	[illegible]	3·2216503	3·4041130	[illegible]	3·8428482	[illegible]	[illegible]	5
56	3·0612111	3·2245230	3·4073382	[illegible]	[illegible]	4·1143675	4·4231224	4
57	[illegible]	[illegible]	[illegible]	[illegible]	3·8511022	[illegible]	[illegible]	3
58	[illegible]	3·2302846	3·4135080	[illegible]	3·8553332	4·1239435	4·4342382	2
59	[illegible]	3·2331736	[illegible]	[illegible]	3·8595135	[illegible]	[illegible]	1
60	3·0715535	3·2360680	3·4203036	[illegible]	3·8637033	4·1335655	4·4454115	0
′	19°	18°	17°	16°	15°	14°	13°	′

CO-SECANTS.

SECANTS.

′	77°	78°	79°	80°	81°	82°	83°	′
0	4·4454115	4·8097343	5·2408431	5·7587705	6·3924532	7·1852965	8·2055090	60
1	[illegible]	[illegible]	5·2486979	5·7682867	6·4042154	7·2001996	8·2249952	59
2	[illegible]	4·8229357	5·2565768	5·7778350	6·4160216	7·2151653	[illegible]	58
3	4·4622803	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57
4	[illegible]	4·8362114	5·2724070	5·7970280	6·4397666	7·2452859	8·2840171	56
5	4·4735993	4·8428774	[illegible]	[illegible]	[illegible]	7·2604417	8·3038812	55
6	[illegible]	4·8405621	5·2883347	5·8163510	6·4636901	7·2756616	8·3238415	54
7	[illegible]	4·8562657	[illegible]	[illegible]	[illegible]	7·2909460	8·3438986	53
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7·3062954	8·3640534	52
9	[illegible]	4·8607299	5·3124109	5·8455820	6·4999148	[illegible]	8·3843065	51
10	[illegible]	4·8764907	5·3204860	5·8553921	6·5120812	7·3371909	[illegible]	50
11	4·5079129	4·8832707	5·3285861	5·8652356	6·5242938	7·3527377	8·4251165	49
12	4·5136844	4·8900700	5·3367114	5·8751128	6·5365528	7·3683512	8·4456629	48
13	4·5194711	4·8968856	5·3448620	5·8850238	6·5488586	7·3840318	8·4663165	47
14	4·5252730	4·9037267	5·3530379	5·8949688	6·5612113	7·3997798	[illegible]	46
15	4·5310903	4·9105844	5·3612393	5·9049479	6·5736112	7·4155959	8·5079304	45
16	4·5369229	4·9174616	5·3694664	5·9149614	6·5860587	7·4314803	8·5288923	44
17	4·5427709	4·9243586	5·3777192	5·9250095	6·5985540	7·4474335	8·5499584	43
18	4·5486344	[illegible]	5·3859979	5·9350922	5·6110973	7·4634560	8·5711295	42
19	4·5545134	4·9382120	5·3943026	5·9452098	6·6236890	7·4795482	8·5924065	41
20	4·5604080	4·9451687	5·4026333	5·9553625	6·6363293	7·4957106	8·6137901	40
21	4·5663183	4·9521453	5·4109903	5·9655504	6·6490184	7·5119437	[illegible]	39
22	[illegible]	4·9591421	5·4193737	5·9757737	6·6617568	7·5282478	8·6568805	38
23	[illegible]	4·9661591	5·4277835	5·9860326	6·6745446	7·5146236	8·6785889	37
24	4·5841439	4·9731964	5·4362199	5·9963274	6·6873822	7·5610713	8·7004071	36
25	4·5901174	4·9802541	5·4446831	6·0066581	6·7002699	7·5775916	8·7223361	35
26	4·5961070	4·9873323	5·4531731	6·0170250	6·7132079	[illegible]	8·7443766	34
27	4·6021126	[illegible]	5·4616901	6·0274282	6·7261965	7·6108516	8·7665295	33
28	4·6081343	5·0015505	5·4702342	6·0378080	6·7392360	7·6275923	[illegible]	32
29	4·6141722	[illegible]	5·4788056	6·0483445	6·7523268	[illegible]	8·8111701	31
30	4·6202263	5·0158517	5·4874043	6·0588580	6·7654691	7·6612976	[illegible]	30
31	4·6262967	5·0230337	5·4960305	6·0694085	6·7786632	7·6782631	[illegible]	29
32	4·6323835	[illegible]	5·5046843	6·0799964	6·7919095	[illegible]	8·8790109	28
33	4·6384867	5·0374607	5·5133659	6·0906219	6·8052082	7·7124227	[illegible]	27
34	4·6446064	[illegible]	5·5220754	6·1012850	6·8185597	7·7296176	8·9248211	26
35	4·6507427	5·0519726	5·5308129	6·1119861	6·8319612	7·7468901	8·9479051	25
36	4·6568956	[illegible]	5·5395786	6·1227253	6·8454222	7·7642406	8·9711095	24
37	[illegible]	5·0665701	5·5483726	6·1335028	6·8589338	[illegible]	8·9944354	23
38	4·6602516	5·0739012	[illegible]	[illegible]	[illegible]	7·7991778	[illegible]	22
39	4·6754548	5·0812539	5·5660460	6·1551736	6·8861195	7·8167656	9·0414553	21
40	4·6816748	[illegible]	5·5749258	6·1660674	6·8997942	7·8344335	[illegible]	20
41	4·6879119	5·0960218	5·5838343	6·1770003	6·9135239	7·8521821	9·0880725	19
42	4·6941660	5·1034131	5·5927719	6·1879725	6·9273089	[illegible]	9·1120700	18
43	4·7004372	[illegible]	[illegible]	[illegible]	[illegible]	7·8879238	9·1360940	17
44	4·7067256	[illegible]	[illegible]	[illegible]	[illegible]	7·9059179	9·1611980	16
45	4·7130313	5·1258309	5·6197599	6·2211275	6·9689994	[illegible]	[illegible]	15
46	4·7193542	5·1333381	5·6288148	6·2322594	6·9830092	7·9421556	9·2090934	14
47	4·7256945	5·1408677	5·6378995	6·2434316	6·9970760	7·9604003	9·2345877	13
48	4·7320524	5·1484190	5·6470140	6·2546416	7·0112001	7·9787298	9·2603145	12
49	4·7384277	5·1559918	5·6561584	6·2658084	7·0253820	[illegible]	[illegible]	11
50	4·7448206	5·1635924	[illegible]	[illegible]	[illegible]	8·0156450	[illegible]	10
51	4·7512312	[illegible]	5·6745380	6·2883295	7·0539205	8·0342321	9·3343006	9
52	4·7576596	5·1788563	[illegible]	[illegible]	[illegible]	[illegible]	9·3595682	8
53	4·7641058	5·1865228	5·6930393	6·3113269	7·0826941	8·0716681	9·3849738	7
54	4·7705699	5·1942125	5·7023360	6·3237884	7·0971700	[illegible]	9·4105184	6
55	4·7770519	5·2019254	5·7116636	6·3342923	7·1117059	8·1094573	9·4362033	5
56	4·7835520	5·2096618	5·7210223	6·3458386	7·1263019	8·1284860	9·4620296	4
57	4·7900702	5·2174216	5·7304121	6·3574276	7·1409587	8·1476048	9·4879984	3
58	4·7966066	5·2252050	5·7398333	[illegible]	[illegible]	[illegible]	9·5141110	2
59	4·8031613	5·2330121	5·7492861	6·3807347	7·1704556	[illegible]	9·5403686	1
60	4·8097343	5·2408431	5·7587705	6·3924532	7·1852965	8·2055090	9·5667722	0
′	12°	11°	10°	9°	8°	7°	6°	′

CO-SECANTS.

′	84°	85°	86°	87°	88°	89°	′
	SECANTS.						
0	9·5667722	11·473713	14·335587	19·107323	28·653708	57·298688	60
1	9·5933233	11·511990	14·395471	19·213970	28·894398	58·269755	59
2	9·6200229	11·550523	14·455859	19·321816	29·139169	59·274308	58
3	9·6468724	11·589316	14·516757	19·430882	29·388124	60·314110	57
4	9·6738730	11·628372	14·578172	19·541187	29·641373	61·391050	56
5	9·7010260	11·667693	14·640109	19·652754	29·899026	62·507153	55
6	9·7283327	11·707282	14·702576	19·765604	30·161201	63·664595	54
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53
8	9·7834124	11·787274	14·829128	19·995241	30·699598	66·113036	52
9	9·8111880	11·827683	14·893226	20·112075	30·976074	67·409272	51
10	9·8391227	11·868370	14·957882	20·230284	31·257577	68·757360	50
11	9·8672176	11·909340	15·023103	20·349893	31·544246	70·160474	49
12	9·8954744	11·950595	15·088896	20·470926	31·836225	71·622052	48
13	9·9238943	11·992137	15·155270	20·593409	32·133663	73·145827	47
14	9·9524787	12·033970	15·222231	20·717368	32·430713	74·735856	46
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45
16	10·010147	12·118522	15·357949	20·960824	33·060300	78·132742	44
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34
27	10·339726	12·605724	16·140087	22·476353	30·000528	104·17574	33
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31
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